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PERSPECTIVES ON THE PRESIDENT'S VISION FOR SPACE EXPLORATION

HEARING

BEFORE THE

COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES

ONE HUNDRED EIGHTH CONGRESS

SECOND SESSION

MARCH 10, 2004

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March 10, 2004

Appendix: Answers to Post-Hearing Questions

PERSPECTIVES ON THE PRESIDENT'S VISION FOR SPACE EXPLORATION

WEDNESDAY, MARCH 10, 2004

House of Representatives,
Committee on Science,
Washington, DC.

The Committee met, pursuant to call, at 10:01 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Sherwood L. Boehlert [Chairman of the Committee] presiding.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, DC 20515

Hearing on

Perspectives on the President's Vision for Space Exploration

Wednesday, March 10, 2004
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

WITNESS LIST

Mr. Norman Augustine
Former Chief Executive Officer, Lockheed Martin
Chair, Advisory Committee on the Future of the U.S. Space Program

Dr. Michael Griffin
President, In-Q-Tel
Former Chief Engineer, NASA
Former Associate Administrator, Exploration Systems, NASA

Dr. Donna Shirley
Director, Science Fiction Museum
Former Manager, Jet Propulsion Laboratory's Mars Program
Former Assistant Dean, University of Oklahoma Aerospace Mechanical Engineering Department

Dr. Larry Young
Apollo Program Professor, Massachusetts Institute of Technology (MIT)
Founding Director of the National Space Biomedical Research Institute (NSBRI)

Dr. Lennard Fisk
Chair, Space Studies Board (SSB), National Academy of Sciences
Chair, Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan
Former Associate Administrator, Space Science and Applications, NASA

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HEARING CHARTER

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Perspectives on the President's Vision for Space Exploration

WEDNESDAY, MARCH 10, 2004
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

I. Purpose

The House Committee on Science will hold a hearing entitled *Perspectives on the President's Vision for Space Exploration* on March 10, 2004, at 10:00 a.m. in room 2318 of the Rayburn House Office Building. The Committee will receive testimony from non-governmental witnesses regarding the President's recently announced space exploration initiative. Charters from two previous, relevant Science Committee hearings are attached.

II. Brief Overview

The witnesses have been asked to give their views on the purpose, structure, costs and technical challenges of the President's initiative and on how it would affect other NASA programs. The goal of the hearing is to get guidance from outside experts on some of the most difficult questions the Congress must consider in evaluating the initiative.

For example, the most difficult obstacle to staying on the Moon for an extended period or to sending a human to Mars may be the impact of spending long periods in space on the human body. Both the radiation and reduced gravity have marked impacts on human physiology. Some scientists (but none on our panel) go so far as to describe these challenges as "insurmountable." The Committee needs to know (among other things) how difficult a hurdle human physiology is, whether NASA's plans to deal with these issues are sufficient, and how research on human physiology in space will influence the development of spacecraft and other technical aspects of the initiative. Several of the witnesses at the hearing will be able to address such matters.

III. Witnesses

Mr. Norman Augustine was the Chief Executive Officer of Lockheed Martin and chair of the Advisory Committee on the Future of the U.S. Space Program, a review of NASA's programs and priorities in 1990 that is still relevant today. Mr. Augustine was asked to testify on:

- Would the initiative achieve an appropriate balance among NASA's activities? In particular, the Augustine Commission viewed space science and Earth science as the top priorities at NASA. Is that still your view and is it reflected in the President's initiative?
- Does the estimated spending through 2020 seem adequate to carry out the President's initiative? Which elements of the President's initiative seem most likely to cost more money or take more time than is currently allotted to them?
- What questions is it most important for Congress to ask as it evaluates the proposed initiative?

Dr. Donna Shirley is the Director of the Science Fiction Museum and a former Manager of the Jet Propulsion Laboratory's Mars Program and former Assistant Dean of the University of Oklahoma Aerospace Mechanical Engineering Department. Dr. Shirley was asked to testify on:

- What are compelling justifications for sending humans into space? Does the President's initiative provide adequate justification for sending humans to the Moon and Mars?
- To what extent would scientific research concerning Mars be aided by a human presence on, or in orbit around that planet?

- Are the International Space Station and the Moon the most appropriate stepping-stones for human space exploration if the ultimate objective is a human landing on Mars? What would be the advantages and disadvantages of a program that was targeted instead on sending a human directly to Mars? To what extent is research on the International Space Station likely to help remove the hurdles to long-duration space flight?
- Does the proposed initiative achieve the proper balance among NASA's activities? Particularly, is the balance between exploration, space science and Earth science, and between human and robotic missions appropriate?

Dr. Michael Griffin is the President of In-Q-Tel. He has nearly 30 years of experience managing space and information technology organizations. He served as NASA's Chief Engineer and Associate Administrator for NASA in the early 1990s. Dr. Griffin was asked to testify on:

- Does the estimated spending through 2020 seem adequate to carry out the President's initiative? Which elements of the President's initiative seem most likely to cost more money or take more time than is currently allotted to them?
- What are the greatest technological hurdles the President's initiative must clear to be successful? To what extent must resolving some technological issues await further fundamental research? For example, how much work on a spacecraft for a Mars mission can be done before more is known about the effect on humans of spending long periods of time in space? How much work can be done before new propulsion technologies are developed?
- Are the International Space Station and the Moon the most appropriate stepping stones for human space exploration if the ultimate objective is a human landing on Mars? What would be the advantages and disadvantages of a program that was targeted instead directly on sending a human to Mars?
- What questions is it most important for Congress to ask as it evaluates the proposed initiative?

Dr. Lennard Fisk is Chair of the Space Studies Board (SSB), National Academy of Sciences. Dr. Fisk led an SSB space policy workshop of experts in the fall 2003 that attempted to define the principal purposes, goals, and priorities of U.S. civil space program. The report from this workshop, "Issues and Opportunities Regarding the U.S. Space Program," was released in January 2004. Fisk is Chair of the University of Michigan Department of Atmospheric, Oceanic, and Space Sciences and former Associate Administrator of NASA's space science and applications department. Dr. Fisk was asked to testify on:

- What are compelling justifications for sending humans into space? Does the President's initiative provide adequate justification for sending humans to the Moon and Mars?
- Are the International Space Station and the Moon the most appropriate stepping-stones for human space exploration if the ultimate objective is a human landing on Mars? What would be the advantages and disadvantages of a program that was targeted instead directly on sending a human to Mars?
- To what extent is research on the International Space Station likely to help remove the hurdles to long-term human presence in space? Does the proposed initiative achieve the proper balance among NASA's activities? Particularly, does the initiative strike the right balance between exploration, space science and Earth science?
- Does the estimated spending through 2020 seem adequate to carry out the President's initiative? Which elements of the President's initiative seem most likely to cost more money or take more time than is currently allotted to them? What questions is it most important for Congress to ask as it evaluates the proposed initiative?

Dr. Larry Young is the Apollo Program Professor at the Massachusetts Institute of Technology (MIT) and Founding Director of the National Space Biomedical Research Institute (NSBRI) in Houston, TX. He is an expert on the physiological challenges for humans in space. Dr. Young was asked to testify on:

- What are the most significant human physiology challenges that must be understood and overcome before humans embark on a mission to Mars or an extended presence on the Moon? How daunting are those challenges and how quickly might they be resolved? How much significant research has been conducted on these issues already and where was that research conducted?

- To what extent could research aboard the International Space Station contribute to resolving critical questions related to human physiology in space? What kinds of experiments would have to be conducted and how long would it likely take before they produced meaningful results? Would additional equipment be needed aboard the Station for the experiments? To what extent could the requisite research be conducted on Earth?
- To what extent would the research budget for the Space Station have to change to accommodate a successful research in human physiology? How many astronauts would be needed aboard the Station to conduct such an agenda?
- How long after experiments began would the International Space Station have to remain in operation to produce meaningful information about human physiology?

Attachments

1. Charter from the February 12, 2004 House Science Committee hearing on *The President's Vision for Space Exploration*.
2. Charter from the October 16, 2003 House Science Committee hearing on *The Future of Human Space Flight*

HEARING CHARTER

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

U.S. Vision for Space Exploration

THURSDAY, FEBRUARY 12, 2004
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

On Thursday, February 12th at 10:00 a.m., the Science Committee will hold a Full Committee hearing on the President's proposed space exploration initiative, which was announced Jan. 14. (A copy of the White House document that outlines the President's vision is attached as Attachment A.)

2. The President's Proposal

The President's plan can be seen as having three distinct, but related aspects. The first aspect concerns current human space flight programs. The President proposes to complete construction of the International Space Station (ISS) by the end of the decade and to retire the Space Shuttle at that point. ISS research is to be reconfigured to focus on questions related to the impact on human health of spending long periods in space. Under the proposal, the U.S. participation in ISS is slated to end around 2016, although the Administration has said that that date may shift. The National Aeronautics and Space Administration (NASA) has also decided to cancel the Shuttle mission that was needed to keep the Hubble Space Telescope in operation past 2007. Ending the Shuttle and Station programs is necessary to free up funds for other aspects of the proposal and to avoid Shuttle recertification in 2010, an expensive process called for by the *Columbia* Accident Investigation Board.

The second aspect of the plan concerns new medium-term goals for human space flight. The central goal is to return to the Moon between 2015 and 2020. To do this, NASA will develop a new Crew Exploration Vehicle (CEV), which will carry humans by 2014. (The CEV may also be used to service the Space Station.)

The third aspect of the plan concerns long-range goals for the years past 2020. The entire plan is geared toward preparing for this period, but what will happen during these years is (perhaps necessarily) left entirely open-ended. The ultimate goals are to send humans to Mars and to increase the commercial exploitation of space. The timing of future exploration is left open and will depend on the pace of technology development and discovery during the years leading up to 2020. The President announced the appointment of a nine-member commission, headed by former Secretary of the Air Force Pete Aldridge, that will focus primarily on recommending what kinds of things ought to be done in the long-run on the Moon and to get to Mars, and how those activities might shape programs in the nearer-term.

3. Overarching Questions

The President's plan raises many fundamental questions about the purposes of the U.S. space program and about the details of how it will be carried out. The overarching questions for the hearing include:

1. What is the *purpose* of the exploration program? To what degree will it be designed to answer scientific research questions? To what degree will it be designed to promote commercialization or national security interests? How high a national priority is exploration for exploration's sake?
2. How much will the President's proposal cost to implement now and in the future? What are the greatest uncertainties in the budget estimates that have been presented? When will those figures become more definite? Are there early points at which progress can reasonably be assessed? What is being done to avoid the inaccurate cost estimates that have plagued the Space Shuttle, Space Station and Orbital Space Plane programs?
3. What *budgetary tradeoffs* will have to be made to fund the President's proposal? Specifically, what will the impact be on NASA's programs in astronomy, outer planetary exploration, Earth science, and aeronautics?

The overall goal of the hearing is to make sure the Committee has clear information on the philosophy and budgetary assumptions that undergird the President's proposal.

4. Witnesses

Mr. Sean O'Keefe, Administrator of the National Aeronautics and Space Administration.

Dr. John Marburger, Director of the Office of Science and Technology Policy.

5. Issues

- **What is the goal of the President's initiative?** Human space travel is inherently expensive and risky compared to robotic missions. Congress needs to decide whether human space travel is a priority that merits continued funding, and obviously that will depend, in part, on what is to be gained. In his Jan. 14 speech, the President said, "We choose to explore space because doing so improves our lives and lifts our national spirit." But the Administration has sent mixed signals about what kinds of improvements will be sought. In some presentations, the Administration has left the impression that exploration is a basic human need, an end in itself—an activity that will be informed by science and may contribute to science, but that will not have a science-driven agenda. In other presentations, the Administration has implied that science is the primary rationale for the President's vision. In other places, commercialization, national security, and the possibility of technological spinoffs have been offered as rationales. None of these reasons is mutually exclusive, but the goals of the program will determine the spending and activities that are undertaken.
- **How much will the President's initiative cost?** The President has been clear that he is not willing to seek massive amounts of new spending to fund the initiative—unlike the approach that was taken during the Apollo program in the 1960s. NASA officials have said that if work does not proceed smoothly, they will extend deadlines rather than increase annual costs. (Moving deadlines would still increase cumulative costs.) The President has proposed a 5.6 percent increase for NASA (to $15.4 billion) for Fiscal Year (FY) 05, by far the largest increase for any R&D agency.

  Figuring out how much the President's initiative would cost is not easy because of the many assumptions that need to be made. Adding to the complexity, NASA has described the costs differently in different documents, using different baselines.

  The most specific figures concern the next five years (FY05–09), over which the President proposes to spend a cumulative total of $87.1 billion on the entire NASA budget. NASA has compared the proposal to two different baselines. In the first comparison, NASA says that over the next five years, the President proposes to spend $1 billion more on the entire NASA budget than NASA had predicted it would spend in February, 2003. (That estimate was made as part of the Presidents's FY04 budget.) In the second comparison, NASA describes the President's proposal as providing $12.6 billion more, cumulatively, over five years for the entire NASA budget compared to what NASA would have received if its spending had been frozen for five years at the FY04 level of about $15 billion. (NASA uses this figure frequently, but there is no evidence that NASA was ever going to face such a freeze.)

  Figuring out how much of the NASA budget will be dedicated to the President's initiative depends on what is included in that spending category. Should it include the Space Shuttle and Space Station? Should it include robotic missions that were planned before the President's announcement, but may contribute to it, or just new ones? NASA, generally, includes all robotic missions that will contribute to the initiative and excludes the Space Shuttle and Space Station. Using those definitions, the initiative would receive $31.4 billion over the next five years. Costs would increase considerably in the subsequent 10 years, and costs cannot even be estimated for the period beyond that because the activities remain undefined. (See Attachment B, although, according to NASA, the chart was designed more for internal purposes than to give a precise picture of out-year spending.)
- **What are the greatest uncertainties in NASA's cost projections?** Of necessity, the proposed budget is based on best guesses of costs for key elements of the President's initiative.

Perhaps the greatest uncertainty remains the cost of continuing to operate the Space Shuttle. Any delay in retiring the Space Shuttle will add significantly to NASA's costs (as well as raising the question of whether the Shuttle should fly without recertification). NASA continues to assume a return to flight this fall, although experts inside and outside the agency are raising doubts about whether that deadline can be met. Once flights resume, NASA plans about five flights a year—a pace that Admiral Gehman, the Chair of the *Columbia* Accident Investigation Board, has said could revive concerns about "schedule pressure" adversely affecting safety. Retiring the Shuttle on schedule may also require using means other than the Shuttle to take up crew and supplies to the Space Station because the Shuttle will be needed to complete Station construction. Shuttle retirement could also be delayed if key portions of the Station, such as the centrifuge being built by the Japanese, are not completed on schedule. (The centrifuge is generally viewed as the most valuable piece of scientific equipment that will be brought to the Station.) NASA is still figuring out the "manifests" for the remaining Shuttle flights—that is, the description of when flights would leave and return and what they would carry.

The costs of developing the CEV, the new vehicle that would take astronauts to the Moon and beyond also are uncertain because development has not yet begun. In some ways, CEV development will build on the Orbital Space Plane (OSP) project that NASA discontinued as part of the President's initiative. The OSP, which was to be designed primarily to take astronauts to the Space Station, was already facing cost overruns in its early design stages, and Congress was raising doubts about its usefulness. NASA now estimates that it will spend $6.5 billion over the next five years on CEV development.

The CEV will also require the development of a new launch system, and NASA has not decided yet how to approach the design of a new launch vehicle. NASA is now estimating that the development of such a vehicle will cost about $5 billion.

Administration officials have said that because the CEV and its launch system will be developed over a longer time period than was allotted for the OSP there will be time to reevaluate costs before becoming overly committed to a particular design. Total CEV development is expected to cost about $15 billion.

The cost of the CEV may be affected by how NASA decides to select a contractor for the program. NASA limited OSP development to two competitors. NASA has not yet made clear whether it will have a more open competition for the CEV.

- **How will the President's initiative affect the rest of NASA's programs?** The Space Sciences budget will continue to grow (from $3.9 billion in FY04 to $5.6 billion in FY09) because many of its robotics missions will be considered part of preparation for human exploration. Most of these missions will be entirely unchanged despite the redesignation. In addition, new lunar missions will be added. Nonetheless, projects totaling about $2.6 billion will be cut from the Space Sciences budget over the next five years (compared to the Administration's February, 2003 projections) by canceling or deferring missions and programs that are considered less important to human exploration. (Other projects are added so that, overall, Space Sciences will receive slightly more over the five-year period than had been planned, if one excludes Project Prometheus, which is being transferred from Space Sciences to another account.) One question is how Space Sciences will fare in the years after FY09 when the costs of a human lunar landing will begin to increase substantially.

  Earth Science would fare far worse, sustaining cuts in FY05 through FY08. Earth Science spending would decline from $1.52 billion in FY04 to $1.47 billion in FY09, a year in which it is slated to receive an increase. NASA Earth Science missions are a major component of the Administration's climate change science program.

  Aeronautics would be essentially flat through the period, increasing in some years and decreasing in others, but ending up in FY09 at $942 million—a drop from the FY04 level of $946 million.

  (See Attachment C for more details.)

- **Why is the Shuttle mission to the Hubble Space Telescope being cancelled?** The Administration is describing the Hubble cancellation as a "close call" made by the Administrator because of safety concerns. The Hubble, which has been enormously successful, is expected to go dark around 2007 without a servicing mission. Many astronomers are lobbying for that mission to occur, and, indeed, before the President's initiative was announced, a panel assembled by the National Academy of Sciences, called for another servicing mission to be added to extend the telescope's life even further. That request became moot with the decision to discontinue the Shuttle in 2010. However, some experts contend that ground-based telescopes have advanced so much in recent years that they can now make up for at least some of the capability that would be lost if the Hubble ceases to function.

  A Shuttle mission to the Hubble is a special case because Hubble missions cannot reach the Space Station, which could be used as a "safe haven" in case of an emergency or the need to inspect or repair the Shuttle. The *Columbia* Accident Investigation Board said that the Shuttle should fly to destinations other than the Space Station only when NASA had developed an "autonomous" inspection and repair capability—that is, a way to inspect without using the Space Station. NASA believes such a capability is probably many years away. As a substitute, NASA examined having a second Shuttle ready to fly a rescue mission, but viewed that as dangerous and prohibitively expensive. However, debate continues among Hubble enthusiasts as to the relative dangers of a mission to the Station and a mission to Hubble.

  NASA acknowledges that there were "secondary" considerations that also led to the cancellation of the Hubble mission, including the need to complete all the Shuttle missions needed for Station construction by 2010.

- **How will the President's initiative change the Space Station program?** As a result of the initiative, NASA is reexamining the entire Station research program. Decisions on the new program may not be made for about a year. The new program will focus on questions of human health. Among the questions this raises are: what research will be discontinued and was any of it of real value? How much will the new research agenda cost? Does the new research really require facilities in space and will it be peer reviewed? Will concerns arise since much of the new research will presumably involve using astronauts as human experimental subjects?

- **How will NASA transport crews to the Station after the Shuttle is retired?** The Administration acknowledges that it has not yet figured out how to get crews to the Station between the retirement of the Shuttle in 2010 and the first flight of the CEV in 2014. (The Shuttle may also be unavailable for crew transfer earlier, if its schedule needs to be devoted entirely to Station construction.)

  The U.S. is already using the Russian Soyuz spacecraft for crew transfer while the Shuttle is grounded. However, it is doing so under an agreement that the Russians will have fulfilled by 2006. Renewing the agreement may require a change in the Iran Nonproliferation Act (INA), which Congress passed in 2000. That Act attempts to prevent the spread of weapons of mass destruction to Iran by prohibiting the purchase of Russian rockets by the U.S. unless the President certifies that no Russian entity is engaged in any sales of missiles or missile systems to Iran. (The INA does not apply to the current agreement.)

  Amending the Act would be controversial, and so far the Administration has hedged its bets, simply saying that the matter is under review.

- **How will NASA carry cargo to and from the Station after the Shuttle is retired?** Similar to the crew situation, NASA has no current plan for getting cargo to the Station after the Shuttle is retired. NASA is using Russian Progress vehicles while the Shuttle is grounded, but continuing to do so indefinitely could require amending the Iran Nonproliferation Act. (See above.) NASA might also rely on Europe or Japan, which are partners in the Space Station and which are developing cargo-carrying spacecraft of their own. But those craft have not yet been flight-tested. Some have suggested that NASA could convert the Space Shuttle itself into a cargo-only craft that could deliver huge loads of cargo to the ISS. But critics have said that such an approach would be much more expensive than flying smaller loads on existing rockets. Finally, NASA might try to purchase the services of commercial rocket firms. But at present no firm has a rocket that can supply the Station, although sev-

eral have indicated a willingness to try to carry small amounts of cargo there. Another complication is that some cargo for the Space Station is very large—major replacement parts, for example—and most craft other than the Shuttle are not big enough to carry such cargo.

6. Questions to witnesses:

In his letter of invitation to appear as a witness, Administrator O'Keefe was asked to address the following questions in his testimony:

(1) What specific activities must be undertaken and milestones achieved over the next twelve months and over the next five years to implement the new initiative? What analysis was performed to ensure that the proposed budget is adequate to accomplish those activities?

(2) Specifically, what changes (in spending and program content) are contemplated in the Shuttle, International Space Station, and Space Science programs as a result of the new initiative?

(3) What is the current status of NASA's thinking about a mission to the Hubble Space Telescope? What changes in spending and in other NASA activities would be necessary to allow one or two more missions to the Hubble?

(4) Are any changes to the Iran Non-proliferation Act, the Space Station Inter-Governmental Agreement or any other agreements required to complete the Space Station? If so, please explain how the Administration plans to inform and consult with the Congress on these changes, including the timetable for any actions that may be necessary.

In his letter of invitation to appear as a witness, Dr. Marburger was given the following information and asked to address the following questions in his testimony:

> In their briefings on the initiative, White House officials have said that you were an active participant in developing the initiative, and that, more specifically, you had reviewed the initiative to ensure that no essential science activities would be sacrificed to pay for it.
>
> In your testimony, you should describe the role you and your staff played in formulating the initiative and why and how you concluded that the initiative would be a net benefit from a scientific point of view. As part of that description, please specifically address the following:
>
> (1) What criteria did you use to determine whether an activity was "essential," and how did you evaluate and balance the differing scientific benefits of existing and potential NASA activities?
>
> (2) To what extent, has and can the International Space Station contribute to science? Did you review any specific new research agenda for the Space Station as part of your evaluation of the overall initiative?
>
> (3) To what extent can scientific research that would be accomplished by manned missions to the Moon be accomplished by space telescopes or by unmanned probes on the Moon?
>
> (4) How would you describe the contributions to science made by the Hubble Space Telescope? How would you assess what would be lost if the Hubble ceases to function earlier than had been planned? How did you weigh those losses against the potential benefits of other activities under the new initiative?"

7. Attachments

Attachment A: *A Renewed Spirit of Discovery: The President's Vision for U.S. Space Exploration*

Attachment B: NASA Budget Projection 2004–2020. (This chart can be viewed in color on the Internet at *http://www.nasa.gov/pdf/54873main_budget_chart_14jan04.pdf*

Attachment C: NASA FY 2005 Budget

Attachment A

A RENEWED SPIRIT OF DISCOVERY

The President's Vision for U.S. Space Exploration

PRESIDENT GEORGE W. BUSH

JANUARY 2004

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Background

From the Apollo landings on the Moon, to robotic surveys of the Sun and the planets, to the compelling images captured by advanced space telescopes, U.S. achievements in space have revolutionized humanity's view of the universe and have inspired Americans and people around the world. These achievements also have led to the development of technologies that have widespread applications to address problems on Earth. As the world enters the second century of powered flight, it is time to articulate a new vision that will define and guide U.S. space exploration activities for the next several decades.

Today, humanity has the potential to seek answers to the most fundamental questions posed about the existence of life beyond Earth. Telescopes have found planets around other stars. Robotic probes have identified potential resources on the Moon, and evidence of water -- a key ingredient for life -- has been found on Mars and the moons of Jupiter.

Direct human experience in space has fundamentally altered our perspective of humanity and our place in the universe. Humans have the ability to respond to the unexpected developments inherent in space travel and possess unique skills that enhance discoveries. Just as Mercury, Gemini, and Apollo challenged a generation of Americans, a renewed U.S. space exploration program with a significant human component can inspire us -- and our youth -- to greater achievements on Earth and in space.

The loss of Space Shuttles *Challenger* and *Columbia* and their crews are a stark reminder of the inherent risks of space flight and the severity of the challenges posed by space exploration. In preparation for future human exploration, we must advance our ability to live and work safely in space and, at the same time, develop the technologies to extend humanity's reach to the Moon, Mars, and beyond. The new technologies required for further space exploration also will improve the Nation's other space activities and may provide applications that could be used to address problems on Earth.

Like the explorers of the past and the pioneers of flight in the last century, we cannot today identify all that we will gain from space exploration; we are confident, nonetheless, that the eventual return will be great. Like their efforts, the success of future U.S. space exploration will unfold over generations.

Goal and Objectives

The fundamental goal of this vision is to advance U.S. scientific, security, and economic interests through a robust space exploration program. In support of this goal, the United States will:

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond;

- Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;

- Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and

- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

Bringing the Vision to Reality

The Administrator of the National Aeronautics and Space Administration will be responsible for the plans, programs, and activities required to implement this vision, in coordination with other agencies, as deemed appropriate. The Administrator will plan and implement an integrated, long-term robotic and human exploration program structured with measurable milestones and executed on the basis of available resources, accumulated experience, and technology readiness.

To implement this vision, the Administrator will conduct the following activities and take other actions as required:

A. Exploration Activities in Low Earth Orbit

Space Shuttle

- Return the Space Shuttle to flight as soon as practical, based on the recommendations of the Columbia Accident Investigation Board;

- Focus use of the Space Shuttle to complete assembly of the International Space Station; and

- Retire the Space Shuttle as soon as assembly of the International Space Station is completed, planned for the end of this decade;

International Space Station

- Complete assembly of the International Space Station, including the U.S. components that support U.S. space exploration goals and those provided by foreign partners, planned for the end of this decade;

- Focus U.S. research and use of the International Space Station on supporting space exploration goals, with emphasis on understanding how the space environment affects astronaut health and capabilities and developing countermeasures; and

- Conduct International Space Station activities in a manner consistent with U.S. obligations contained in the agreements between the United States and other partners in the International Space Station.

B. Space Exploration Beyond Low Earth Orbit

The Moon

- Undertake lunar exploration activities to enable sustained human and robotic exploration of Mars and more distant destinations in the solar system;

- Starting no later than 2008, initiate a series of robotic missions to the Moon to prepare for and support future human exploration activities;

- Conduct the first extended human expedition to the lunar surface as early as 2015, but no later than the year 2020; and

- Use lunar exploration activities to further science, and to develop and test new approaches, technologies, and systems, including use of lunar and other space resources, to support sustained human space exploration to Mars and other destinations.

Mars and Other Destinations

- Conduct robotic exploration of Mars to search for evidence of life, to understand the history of the solar system, and to prepare for future human exploration;
- Conduct robotic exploration across the solar system for scientific purposes and to support human exploration. In particular, explore Jupiter's moons, asteroids and other bodies to search for evidence of life, to understand the history of the solar system, and to search for resources;
- Conduct advanced telescope searches for Earth-like planets and habitable environments around other stars;
- Develop and demonstrate power generation, propulsion, life support, and other key capabilities required to support more distant, more capable, and/or longer duration human and robotic exploration of Mars and other destinations; and
- Conduct human expeditions to Mars after acquiring adequate knowledge about the planet using robotic missions and after successfully demonstrating sustained human exploration missions to the Moon.

C. Space Transportation Capabilities Supporting Exploration

- Develop a new crew exploration vehicle to provide crew transportation for missions beyond low Earth orbit;

  - Conduct the initial test flight before the end of this decade in order to provide an operational capability to support human exploration missions no later than 2014;

- Separate to the maximum practical extent crew from cargo transportation to the International Space Station and for launching exploration missions beyond low Earth orbit;

  - Acquire cargo transportation as soon as practical and affordable to support missions to and from the International Space Station; and

  - Acquire crew transportation to and from the International Space Station, as required, after the Space Shuttle is retired from service.

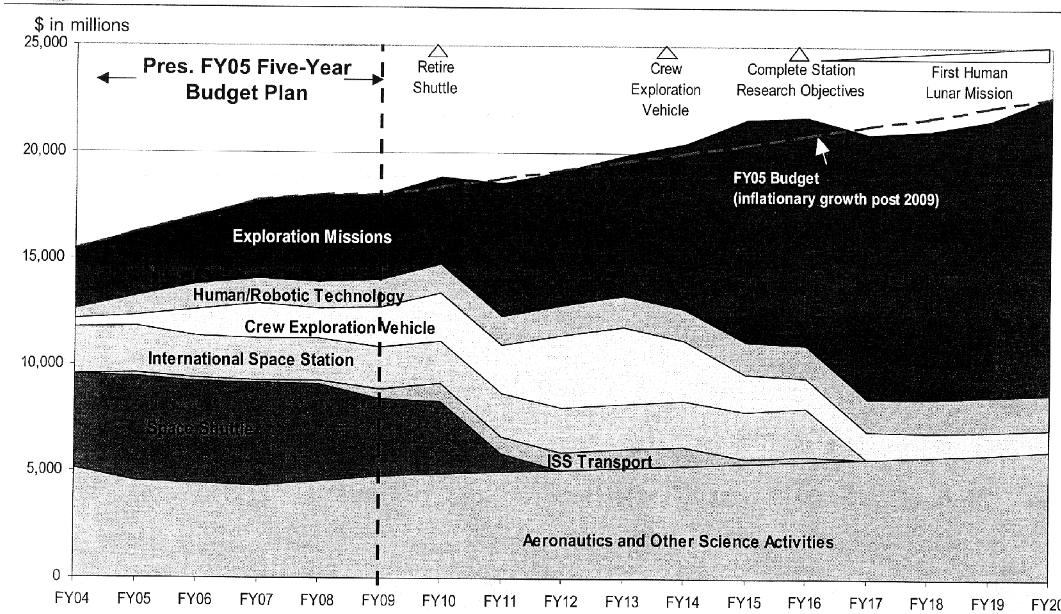
D. International and Commercial Participation

- Pursue opportunities for international participation to support U.S. space exploration goals; and

- Pursue commercial opportunities for providing transportation and other services supporting the International Space Station and exploration missions beyond low Earth orbit.

Attachment B

Strategy Based on Long-Term Affordability



NOTE: Exploration missions – Robotic and eventual human missions to Moon, Mars, and beyond
Human/Robotic Technology – Technologies to enable development of exploration space systems
Crew Exploration Vehicle – Transportation vehicle for human explorers
ISS Transport – US and foreign launch systems to support Space Station needs especially after Shuttle retirement

Attachment C

NASA's FY2005 Budget
($ in millions)

By Appropriations Account / By Enterprise / By Theme	FY 2004 Enacted	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	Delta FY04-05 $	Delta FY04-05 %	Delta FY05-09 $	Delta FY05-09 %	Total FY05-09
Exploration, Science & Aeronautics	7,831	7,760	7,869	8,320	8,900	9,091	-71	-0.9%	1,331	17.2%	41,941
Space Science	3,944	4,138	4,404	4,906	5,520	5,561	195	4.9%	1,423	34.4%	24,528
Solar Systems Exploration	1,302	1,187	1,202	1,300	1,392	1,438	-115	-8.8%	252	21.2%	6,519
Mars Exploration	595	691	724	944	1,188	1,268	96	16.1%	578	83.6%	4,815
Lunar Exploration		70	135	280	375	420	70	n/a	350	500.0%	1,280
Astronomical Search for Origins	894	1,067	1,196	1,212	1,182	927	173	19.4%	-140	-13.1%	5,584
Structure & Evolution of the Universe	404	378	365	382	425	457	-26	-6.4%	79	20.9%	2,007
Sun-Earth Connections	749	746	781	788	958	1,051	-3	-0.4%	305	40.9%	4,324
Earth Science	1,525	1,485	1,390	1,368	1,343	1,474	-40	-2.6%	-11	-0.7%	7,060
Earth System Science	1,451	1,409	1,313	1,290	1,266	1,397	-43	-2.9%	-12	-0.8%	6,675
Earth Science Applications	74	77	77	77	77	77	3	3.4%	1	0.7%	385
Biological & Physical Research	965	1,049	950	938	941	944	84	8.7%	-105	-10.0%	4,822
Biological Sciences Research	356	492	499	496	500	502	136	38.2%	10	2.0%	2,489
Physical Sciences Research	350	300	220	210	210	210	-50	-14.3%	-90	-30.0%	1,150
Research Partnerships & Flight Supt	259	257	232	232	231	232	-2	-0.8%	-25	-9.7%	1,184
Aeronautics	946	919	957	938	926	942	-27	-2.9%	23	2.5%	4,682
Aeronautics Technology	946	919	957	938	926	942	-27	-2.9%	23	2.5%	4,682
Education	164	169	169	171	170	170	5	3.0%	1	0.6%	849
Education	164	169	169	171	170	170	5	3.0%	1	0.6%	849
Earmarks**	287										
Exploration Capabilities	7,521	8,456	9,104	9,465	9,070	8,911	936	12.4%	455	5.4%	45,006
Exploration Systems*	1,563	1,782	2,579	2,941	2,809	3,313	219	14.0%	1,531	85.9%	13,424
Human & Robotic Technology	655	1,094	1,318	1,317	1,386	1,450	439	67.1%	356	32.6%	6,565
Transportation Systems	909	689	1,261	1,624	1,423	1,863	-220	-24.2%	1,174	170.5%	6,860
Space Flight	5,857	6,674	6,525	6,524	6,261	5,598	817	14.0%	-1,076	-16.1%	31,582
Space Station	1,497	1,863	1,764	1,780	1,779	2,115	366	24.5%	252	13.5%	9,301
Space Shuttle	3,928	4,319	4,326	4,314	4,027	3,030	391	10.0%	-1,289	-29.8%	20,016
Space Flight Support	432	492	435	430	456	453	60	13.9%	-39	-7.9%	2,266
Earmarks**	101										
Inspector General	27	28	29	30	31	32	1	3.7%	4	14.3%	150
TOTAL	15,378	16,244	17,002	17,815	18,001	18,034	866	5.6%	1,790	11.0%	87,097
year to year increase		5.6%	4.7%	4.8%	1.0%	0.2%					

*In FY2004 Exploration Systems replaces Crosscutting Technologies
**FY2004 budget column does not allocate earmarks across Enterprises
NOTE: May not add due to rounding

HEARING CHARTER

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

The Future of Human Space Flight

THURSDAY, OCTOBER 16, 2003
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

The Committee on Science will hold a hearing on *The Future of Human Space Flight* on October 16, 2003 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building. The hearing will examine the rationale for human presence in space, the feasibility and cost of various potential long-term goals, and the near-term implications of establishing these goals.

2. Overarching Questions

The witnesses will outline their perspectives on human space flight and lay out various options that could be pursued. Overarching questions that will be addressed are:

- What is the U.S. likely to gain by the proposed options for human space flight and why could such gains not be obtained in other ways?
- What is a rough estimate of the costs of pursuing any of the proposed options? What is the approximate amount of time that it would take to achieve the goals of the proposed options?
- What are the technical hurdles that must be overcome in pursuing the options and the steps that must be taken to overcome those hurdles? (i.e., are there intermediate program goals and when might these be achieved?)
- What are the implications of the options for the current human space flight program? To what degree does the current program contribute to, or impede other options that could be pursued?

3. Key Issues

In the aftermath of the *Columbia* tragedy and the *Columbia* Accident Investigation Board report, the Nation has a rare opportunity to re-examine the vision and goals of the human space flight program. The following are some of the key issues:

Is there a compelling reason for human presence in space? The Apollo program to send a man to the Moon was clearly tied to a broader national goal, winning the Cold War. Today, NASA's human space flight program lacks a similar goal and is not tied to any national imperative. While NASA officials often argue that a human presence in space is necessary to carry out scientific research, even many advocates of human space flight suggest that science alone is not a compelling justification because much research can be conducted with unmanned probes. Instead advocates point to other rationales, including the human imperative to explore, a need for a strategic presence ,in space, the potential for technological spinoffs, and the possible development of human colonies in space, which they say could be especially important in the event of a natural or human-induced calamity on Earth.

What are the appropriate roles for robotic exploration and human exploration? Robotic spacecraft have landed on the Moon and Mars, and (in the case of the Soviet Union) on Venus. Robotic spacecraft have flown by every planet in the Solar System with the exception of Pluto, and NASA is currently developing a mission to that planet. Robotic spacecraft provide a wealth of scientific information and typically cost a fraction of what a human mission costs. In January 2004, NASA's Mars Exploration Rovers Mission will land two identical rovers, named Spirit and Opportunity, on the Martian surface to search for clues of water. This mission cost less than $1 billion. In some cases, robotic spacecraft and human missions work together to perform complementary tasks, such as when astronauts service and repair the Hubble Space Telescope or when robotic missions are used to scout out landing sites for human missions as was done before Apollo. Key issues include: What is

the appropriate balance between robotic and human missions? What activities can only be accomplished with humans? Should NASA focus its efforts on robotic exploration until a suitable purpose can be developed and agreed upon for human exploration?

How would the Space Shuttle, the International Space Station and other aspects of the current human space flight program fit with any vision for NASA's future? Neither the Space Shuttle nor the Space Station has met its primary original goal. The Shuttle, for example, has not led to low-cost, routine, and reliable access to space; the Space Station is no longer being designed to provide a space-based platform to assemble and launch missions beyond Earth's orbit. Some advocates of a bolder mission for NASA argue that both the Shuttle and the Space Station consume large amounts of money simply to send humans repeatedly into Low Earth Orbit (LEO) without moving toward any more ambitious or compelling goal. Others point out that the Space Station could contribute to future missions by providing data on how the human body reacts to prolonged stays in space. It is not clear how the Orbital Space Plane—the next vehicle on the drawing boards at NASA—would contribute to future missions. While NASA has talked about having the Space Plane contribute to longer-range goals, it is being designed only to ferry astronauts back and forth to the Space Station.

What technological barriers must be overcome? Human space flight is inherently dangerous. Human space exploration beyond Earth orbit is particularly hazardous because the radiation environment beyond the protective Van Allen belts[1] is much greater than the radiation levels experienced on the Space Station. Furthermore, the increased distance from Earth makes it impractical, and in some cases impossible, to return quickly if a problem arises. Also, it has been clearly demonstrated that near-zero gravity has a slowly debilitating effect on human physiology. For example, astronauts can lose between 6 and 24 percent of their bone mass over the course of a year in space.[2] Depending on the duration and destination of the mission, improved technologies for propulsion, power, and life support systems may need to be developed.

What can we afford? The U.S. spends more than $6 billion annually on human space flight, including the Space Shuttle, Space Station, and Space Station research. This amount accounts for more than 40 percent of NASA's budget. Both Space Station and Space Shuttle have cost significantly more than originally expected and, following the *Columbia* tragedy, Shuttle costs are likely to increase. A large and sustained investment is likely to be necessary for any ambitious human space flight mission to succeed. NASA spending accounted for as much as 3.5 percent of the entire federal budget during the Apollo program, but today represents less than one percent of federal spending. Is the U.S. prepared to make NASA a sustained funding priority?

4. Background—Previous Studies on Future Goals for Space[3]

Over the last 40 years, numerous studies, commissions, and task forces have attempted to address the future of the U.S. civil space program, and the human space flight program in particular. The following provides a summary of several key studies.

National Commission on Space—(The Paine Commission, 1986)

In 1984, Congress created a commission to look at the long-term future of the civil space program. Chaired by former NASA Administrator Thomas O. Paine, the 15-member panel spent a year developing a 50-year plan. This plan was detailed in their report *Pioneering the Space Frontier*. In summary, the Commission called for the United States to lead the way in opening the inner solar system for science, exploration, and development. The Commission envisioned the establishment of bases on the Moon and Mars and the creation of a routine transportation system among the Earth, Moon, and Mars. The Commission emphasized that it was not trying to predict the future, but rather show what the United States could do if it chose to do so. The Commission envisioned human exploration missions returning to the Moon by 2005 and going to Mars by 2015. The report detailed a program involving

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[1] The Van Allen Belts are layers of charged high-energy particles located above Earth's atmosphere (4000 to 40,000 miles up). The Earth's magnetic field traps the particles and protects astronauts on the Space Station from cosmic radiation.

[2] http://spaceresearch.nasa.gov/general_info/issphysiology.html

[3] Based on Congressional Research Service Report 95–873, Space Activities of the United States, CIS [the Commonwealth of Independent States] and other Launching Countries/Organizations 1957–1994, Marcia S. Smith, Specialist in Science and Technology Policy

both robotic and human exploration, acting synergistically to achieve the goal of opening the solar system. The report did not provide a cost estimate for carrying out its recommendations, but identified three principal benefits: (1) advancement of science and technology; (2) economic benefit of low-cost launch systems; and (3) opening up new worlds on the space frontier.

Leadership and America's Future in Space—(The Ride Report, 1987)

Astronaut Sally Ride's report *Leadership and America's Future in Space* was prepared as an internal NASA report. The report stated that the U.S. had lost its leadership in space and was in danger of being surpassed by other countries. The report argued that to regain leadership the U.S. space program must have two attributes: (1) a sound program of scientific research and technology development; and (2) significant and visible accomplishments. The report detailed four programs areas for comparatively near-term (15–20 year) activities: Mission to Planet Earth (now called Earth Science), robotic exploration of the solar system, a Moon base, and sending humans to Mars. The report recommended that NASA pursue programs in each of these areas. The report envisioned humans returning to the Moon by 2000, preceded by robotic probes to select a site for the Moon base. The report proposed one-year expeditionary missions to Mars between 2005 and 2010. The report concluded that settling Mars should be an eventual goal. As a result of the Ride report, NASA established the Office of Exploration to investigate long-range proposals for human exploration to the Moon and Mars.

President Bush's Space Exploration Initiative (SEI)—1989–1993

On July 20, 1989, the 20th anniversary of the first Apollo landing on the Moon, President Bush made a major space policy address, endorsing the goal of returning humans to the Moon and then going on to Mars "in the 21st Century." The program was referred to as the Space Exploration Initiative (SEI). At the time the President made his statement in 1989, the Director of the Office of Management and Budget suggested that the program would cost $400 billion over 30 years. While Congress endorsed the philosophy of the program, Congress was reluctant to approve the program because of the expected cost. The SEI program was formally terminated in 1993 and the NASA Office of Exploration was dismantled.

The Advisory Committee on the Future of the U.S. Space Program—(The Augustine Report, 1990)

In 1990, concerns about problems with several NASA programs (Hubble Space Telescope's flawed mirror, hydrogen leaks grounding the Shuttle for five months, and several issues with the Space Station program) prompted the White House to strongly encourage NASA to establish an outside advisory panel to reviews its programs and management. The panel was chaired by then-Chairman and CEO of Martin Marietta Inc., Norman Augustine. The panel recommended that NASA's budget increase by 10 percent per year after inflation. The report recommended activities for NASA in five major areas. They were: (1) Space Science (e.g., Hubble Space Telescope), which the report said should be NASA's highest priority and be maintained at 20 percent of NASA's overall budget; (2) Mission to Planet Earth (now called Earth Science); (3) Mission from Planet Earth, which would include robotic spacecraft needed as precursors to human exploration. The long-term goal would be human exploration of Mars. No specific timetable for this mission was set. Instead, the panel urged NASA to adopt a philosophy of "go-as-you-pay;" (4) space technology, (i.e., design of subsystems and materials for spacecraft) for which the report said spending should double or triple; and (5) development of a "heavy lift" unmanned, expendable launch vehicle to complement the Space Shuttle. The panel stated that if the 10 percent budget increases were not available the programs should be prioritized as follows: (1) Space Science; (2) Mission to Planet Earth; (3) heavy lift launch vehicle; (4) technology development: and (5) Mission from Planet Earth.

National Academy of Sciences Study—The Human Exploration of Space, 1997

In 1997, the Academy undertook a study of the role of science in human space exploration. The study examined scientific activities that must be conducted before human exploration beyond Earth orbit could be practically undertaken and science that would be enabled or facilitated by human presence. The study concluded that clear goals must be set and that an integrated science program, with the appropriate balance of human and robotic missions, to collect relevant data to enable future missions beyond Earth orbit should be pursued.

Columbia Accident Investigation Board (CAIB)—(The Gehman Report, 2003)

In its August report, the CAIB concluded that there was a problematic mismatch between NASA's missions and its budget. This occurred because NASA and/or Congress failed to scale back NASA's missions when funding did not match requested levels or when initial cost estimates proved to be inaccurate. The CAIB also pointed out that "for the past three decades, NASA has suffered because of the "lack. . .of any national mandate providing NASA a compelling mission requiring human presence in space." The CAIB stated that investments in a "next generation launch vehicle" will be successful only if the investment "is sustained over the decade; if by the time a decision to develop a new vehicle is made there is a clearer idea of how the new space transportation system fits into the Nation's overall plans for space; and if the U.S. Government is willing at the time a development decision is made to commit the substantial resources required to implement it." For further CAIB comments, see Attachment A.

5. Witnesses

Dr. Michael Griffin is the President and Chief Operating Officer of In-Q-Tel. He has nearly 30 years of experience managing information and space technology organizations. Dr. Griffin has served as Executive Vice President and CEO of Magellan Systems Division of Orbital Sciences Corporation, and as EVP and General Manager of Orbital Space Systems Group. Prior to that he served as both the Chief Engineer and Associate Administrator for Exploration at NASA, and at the Pentagon as the Deputy for Technology of the Strategic Defense Initiative Organization.

Dr. Wesley T. Huntress is the Director of the Carnegie Institution's Geophysical Laboratory. From 1993 to 1998 he was NASA's Associate Administrator for Space Science. In this position he was responsible for NASA's programs in Astrophysics, Planetary Exploration and Space Physics. Previously, he was Director of the Solar System Exploration Division. Dr. Huntress earned his B.S. in Chemistry at Brown University in 1964, and his Ph.D. in Chemical Physics at Stanford University in 1968. He is the recipient of a number of honors including the NASA Exceptional Service Medal.

Dr. Matthew B. Koss is an Assistant Professor of Physics of the College of Holy Cross in Worcester, Massachusetts. He has been the Lead Scientist on several Space Shuttle microgravity flight experiments flown on STS–62, STS–75, and STS–87. He received an AB degree from Vassar College in 1983 and a Ph.D. in Experimental Condensed Physics from Tufts University in 1989.

Dr. Alex Roland is Professor of History and Chairman of the Department of History at Duke University, where he teaches military history and the history of technology. From 1973 to 1981 he was a historian with NASA. He has written and lectured widely on the United States manned space flight program. He is past President of the Society for the History of Technology and of the U.S. National Committee of the International Union for the History and Philosophy of Science.

Dr. Bruce Murray is Professor Emeritus of Planetary Science and Geology at the California Institute of Technology. He was Director of the NASA/Caltech Jet Propulsion Laboratory from 1976 to 1982, which included the Viking landings on Mars and the Voyager mission through Jupiter and Saturn encounters. In 1979, he, the late Carl Sagan, and Louis Friedman founded The Planetary Society. He has published over 130 scientific papers and authored or co-authored six books. He received his college education at M.I.T., culminating in the Ph.D. in 1955.

6. Witness Questions

All the witnesses except Dr. Koss were asked to layout an option that they believed NASA should pursue and answer the following questions in their testimony:

- What is the U.S. likely to gain by your proposed option for human space flight and why could such gains not be obtained in other ways?
- What is a rough estimate of the costs of pursuing your proposed option? What is the approximate amount of time that it would take to achieve the goals of your proposed option?
- What are the technical hurdles that must be overcome in pursuing your option and the steps that must be taken to overcome those hurdles? (i.e., are there intermediate program goals and when might these be achieved?)
- What are the implications of your option for the current human space flight program? To what degree does the current program contribute to, or impede other options that could be pursued?

Dr. Koss was asked to answer these questions:

- How necessary is it to have the participation of people in space for successful research in material sciences? What proportion, if any, of the experiments now conducted on the Space Shuttle or Space Station could be conducted autonomously with unmanned systems? If researchers no longer had access to the Space Shuttle or Space Station how would advancement in the material sciences be affected?
- What alternatives exist to carry to orbit micro-gravity experiments that could be conducted autonomously if the Space Shuttle or Space Station were not available for whatever reason? If none, how much would it cost NASA to provide researchers such an alternative?
- To what extent, if any, would a more ambitious mission for NASA, such as sending people back to the Moon or to Mars, be likely to provide material science researchers with unique opportunities for experimentation?

7. Attachments:

- Attachment A: Excerpt from the *Columbia* Accident Investigation Board Report.
- Attachment B: NASA's five-year budget runout.
- Attachment C: Editorial by Dr. Matthew B. Koss.

ATTACHMENT A

Excerpted from the Columbia *Accident Investigation Board Report Volume 1, Chapter 9, August 2003.*

"Lack of a National Vision for Space"

In 1969 President Richard Nixon rejected NASA's sweeping vision for a post-Apollo effort that involved full development of low-Earth orbit, permanent outposts on the Moon, and initial journeys to Mars. Since that rejection, these objectives have reappeared as central elements in many proposals setting forth a long-term vision for the U.S. Space program. In 1986 the National Commission on Space proposed "a pioneering mission for 21st century America: To lead the exploration and development of the space frontier, advancing science, technology, and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars."[4] In 1989, on the 20th anniversary of the first lunar landing, President George H.W. Bush proposed a Space Exploration Initiative, calling for "a sustained program of manned exploration of the solar system."[5] Space advocates have been consistent in their call for sending humans beyond low-Earth orbit as the appropriate objective of U.S. space activities. Review committees as diverse as the 1990 Advisory Committee on the Future of the U.S. Space Program, chaired by Norman Augustine, and the 2001 International Space Station Management and Cost Evaluation Task Force have suggested that the primary justification for a space station is to conduct the research required to plan missions to Mars and/or other distant destinations. However, human travel to destinations beyond Earth orbit has not been adopted as a national objective. The report of the Augustine Committee commented, "It seems that most Americans do support a viable space program for the Nation—but no two individuals seem able to agree upon *what* that space program should be."[6] The Board observes that none of the competing long-term visions for space have found support from the Nation's leadership, or indeed among the general public. The U.S. civilian space effort has moved forward for more than 30 years without a guiding vision, and none seems imminent. In the past, this absence of a strategic vision in itself has reflected a policy decision, since there have been many opportunities for national leaders to agree on ambitious goals for space, and none have done so."

[4] National Commission on Space Pioneering the Space Frontier: An Exciting Vision of Our Next Fifty Years in Space, Report of the National Commission on Space (Bantam Books, 1986), p. 2.

[5] President George H.W. Bush, "Remarks on the 20th Anniversary of the Apollo 11 Moon Landing," Washington, D.C., July 20, 1989.

[6] "Report of the Advisory Committee on the Future of the U.S. Space Program," December 1990, p. 2.

ATTACHMENT B

NASA FY 2004 Budget
(Budget Authority - $ millions)

By Appropriation Account / By Enterprise / By Theme	Business as Usual	FULL COST					
	Pres. Req. FY03	Est. Pres. Req. FY03	FY04	FY05	FY06	FY07	FY08
Science, Aero, & Exploration	**7,015**	**7,101**	7,661	**8,269**	**8,746**	**9,201**	**9,527**
Space Science	**3,414**	**3,468**	**4,007**	**4,601**	**4,952**	**5,279**	**5,573**
Solar System Exploration	976	1,046	1,359	1,648	1,843	1,952	2,054
Mars Exploration	496	551	570	607	550	662	685
Astronomical Search for Origins	698	799	877	968	1,020	1,022	1,061
Structure &Evolution of the Univ.	331	398	432	418	428	475	557
Sun-Earth Connections	544	674	770	959	1,111	1,169	1,216
Institutional	370	--	--	--	--	--	--
Earth Science	**1,628**	**1,610**	**1,552**	**1,525**	**1,598**	**1,700**	**1,725**
Earth System Science	1,249	1,529	1,477	1,440	1,511	1,606	1,629
Earth Science Applications	62	81	75	85	87	94	96
Institutional	318	--	--	--	--	--	--
Biological & Physical Research	**842**	**913**	**973**	**1,042**	**1,087**	**1,118**	**1,143**
Biological Sciences Research	245	304	359	399	453	456	481
Physical Sciences Research	247	351	353	392	380	409	401
Commercial Research & Support	170	254	261	251	254	253	262
Institutional + AM + SAGE	181	3	--	--	--	--	--
Aeronautics	**986**	**949**	**959**	**932**	**939**	**934**	**916**
Aeronautics Technology	541	949	959	932	939	934	916
Institutional	445	--	--	--	--	--	--
Education Programs	**144**	**160**	**170**	**169**	**169**	**170**	**170**
Education	144	160	170	169	169	170	170
Space Flight Capabilities	**7,960**	**7,875**	7,782	**7,746**	**7,881**	**8,066**	**8,247**
Space Flight	**6,131**	**6,107**	6,110	**6,027**	**6,053**	**6,198**	**6,401**
Space Station	1,492	1,851	1,707	1,587	1,586	1,606	1,603
Space Shuttle	3,208	3,786	3,968	4,020	4,065	4,186	4,369
Space Flight Support	239	471	432	419	402	407	429
Institutional	1,192	--	--	--	--	--	--
Crosscutting Technology	**1,829**	**1,768**	**1,673**	**1,720**	**1,828**	**1,868**	**1,846**
Space Launch Initiative	879	1,150	1,065	1,124	1,221	1,257	1,224
Mission & Sci. Measurement Tec	275	434	438	435	439	439	444
Innov. Tech Trans. Partnership	147	183	169	161	168	172	179
Institutional	528	--	--	--	--	--	--
Inspector General	**25**	**25**	26	**28**	**29**	**30**	**31**
TOTAL	**15,000**	**15,000**	15,469	**16,043**	**16,656**	**17,297**	**17,806**

ATTACHMENT C

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June 29, 2003, Sunday, Late Edition—Final

How Science Brought Down the Shuttle

BY MATTHEW B. KOSS

Matthew B. Koss is an assistant professor of physics at the College of the Holy Cross.

As a scientist whose experiments were carried out on three missions of the Space Shuttle *Columbia,* I have been following with great interest the findings of the board looking into the Shuttle's demise. Though a piece of foam may be found ultimately responsible, as the *Columbia* Accident Investigation Board announced last week, on some level I feel personally culpable for the loss of the seven astronauts. In-orbit experiments like mine have been used to justify manned space projects like the Shuttle for decades.

The truth is that the vast majority of scientific experiments conducted in orbit—including my own—do not require astronauts. The main reason for in-orbit experimentation is to observe how a scientific process works without gravity-driven influences. But almost all of these tests, save those that must be done on humans, can be controlled from the ground via computer or by robots in space. In fact, some of the best work is done this way when the crew is asleep, not moving about and causing vibrations.

To be sure, a lot of important science has been conducted in orbit. For example, research on the large single crystals of silicon that are at the heart of computer chips arose from the many detailed studies of crystal growth on the Space Shuttle. But, in fact, experiments like these are often more efficient and yield more fruitful results when done without the involvement of astronauts.

The science performed on the Shuttle can be classified as either a payload or a mid-deck laboratory experiment. Payload experiments are self-contained packages mounted in the payload bay, the wide open space in the back of the Shuttle. They either run autonomously or are controlled remotely via computers on the ground. Laboratory experiments are performed in the mid-deck or Spacelab module, and are done by the astronauts with computer assistance from the ground.

My experiments, on the fundamentals of how liquids turn into solids, were originally planned for the mid-deck, where they would be controlled by an astronaut who was scheduled to do eight tests. But because of launching delays, the project was changed to a payload experiment that would perform tests autonomously. During the flight, initial data was transmitted to the ground and analyzed by me and my colleagues. Performing the experiment remotely, without crew involvement, allowed us to do 63 test runs.

(Remote-controlled experiments may seem to contradict images we have grown accustomed to—of happy, busy astronauts manipulating scientific equipment or talking about the science on-board, or occasionally reporting on the objectives of experiments. But this public image of astronauts as laboratory scientists working on their own experiments is a bit misleading. Since the Mercury 7 pioneers, the astronaut corps has served one overriding political and public relations purpose—to sell the space program.

The idea of using the Space Shuttle as a scientific laboratory actually came about after the Shuttle's design was already in place. The Shuttle program was conceived in the waning days of the Apollo program as the best option to continue a manned space program at the lowest cost. However, without a place to shuttle to, and not nearly enough satellites that needed a Shuttle to launch or repair them, the Shuttle program succeeded in doing little beyond creating a human presence in space. The idea of the Shuttle as an in-orbit lab was used as a justification for investment in its future.

Similarly, the International Space Station has been aggressively marketed as a science lab. In fact, the Station is seriously flawed in that too much crew time needs to be committed to Station maintenance, and too many of the planned experiments depend on crew operations when they could more effectively be done without them. In many cases, the crew is needed only to deploy an autonomous experiment.

Because of cost overruns and budget problems, the Station's crew was cut back to three from the planned seven. Originally, 120 astronaut-hours per week were to have been devoted to science; this has been cut back to 20 hours per week. With

the Shuttle program grounded once again, it has become even more difficult to exchange crews, replace experiments or repair and refurbish equipment.

Scientific experimentation in space can be safer and more cost effective using long-duration remote controlled orbital spacecraft. At the outset, the costs of developing this technology may appear greater than simply perfecting the Shuttle. But if you do not need to provide a safe and sustaining environment for astronauts—making sure takeoffs and landings aren't too fast, providing enough food and oxygen—the overall cost will be significantly reduced.

If NASA is not able to convince the public of the importance of science in orbit without astronaut involvement, then so be it. At least America's refusal to support science would be honest, would not needlessly endanger human lives or compromise the integrity of science and scientists.

We will always need astronauts to assume certain risks to develop the technology that allows for human exploration of space. The space shuttles and space stations may be necessary to fulfill that mission. However, we need to separate the goal of scientific experimentation from the desire for space exploration. I hope that the unfortunate death of the *Columbia* astronauts will forever sever the false link that has been created between the two.

Astronauts do not risk their lives to perform scientific experiments in space. They fly to fulfill a much more basic and human desire—to experience the vastness of space.

Chairman BOEHLERT. We are going to start right away as some of our Members are coming in. We are told that in 15 minutes or so we are going to be rudely interrupted by the bells calling us to the Floor. That is unfortunate, but off we go.

The hearing will come to order. I want to welcome everyone here for our second hearing on the President's proposed space exploration initiative. I am going to keep my comments brief, because we are going to have to break for votes soon, and because my concerns with the President's proposal should be well understood by now.

I think all I need to say about my views this morning is to reiterate that I remain undecided about whether and how to undertake the exploration program. I would add that, as the outlines of the likely fiscal year 2005 budget becomes clearer, my questions about the initiative only become more pressing.

We could not ask for a better panel to help answer those questions than the one we have before us today. I am truly honored to have such a distinguished group of experts here, people with long and deep experience with the space program who have nonetheless remained probing and independent thinkers about space policy.

The panelists have also done us the great and all too rare service in their testimony of responding very directly to the specific questions that were posed to them, and that will help us have a focused and truly interactive session this morning with, I hope, plenty of discussion among the witnesses themselves.

The questions we posed are some of the fundamental ones that Congress must consider as it evaluates the initiative: Exactly what role should humans play in exploration? To what extent can the International Space Station and the Moon play a useful role in a program whose ultimate goal is Mars? Are the cost and schedule estimates realistic? Can the program be funded without doing undue harm to other NASA programs? What challenges must we meet to enable humans to remain healthy during long stays in space, and how can we meet those challenges?

We have also asked for guidance on what other questions Congress should be asking, and I can think of no more distinguished people than the people before us today to address those questions to.

Our witnesses this morning, all of whom support the initiative in principle, have a variety of thoughtful answers to our questions. I very much look forward to hearing from them.

Mr. Gordon.

[The prepared statement of Mr. Boehlert follows:]

PREPARED STATEMENT OF CHAIRMAN SHERWOOD BOEHLERT

I want to welcome everyone here for our second hearing on the President's proposed space exploration initiative. I'm going to keep my comments brief because we're going to have to break for votes soon, and because my concerns with the President's proposal should be well understood by now.

I think all I need to say about my views this morning is to reiterate that I remain undecided about whether and how to undertake the exploration program. I would add that, as the outlines of the likely fiscal 2005 budget become clearer, my questions about the initiative only become more pressing.

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Mr. Gordon.

Mr. GORDON. Thank you, Mr. Chairman, and good morning. Welcome to the witnesses. There are many important issues associated with the President's space exploration initiative, and I look forward to hearing your perspectives.

I come to this hearing as one who believes that it is important for the U.S. civil space program to have challenges and long-term goals. And also, I want to welcome—or welcomed the President's January the 14th speech announcing some specific exploration goals, including returning to the Moon and eventually human missions to Mars.

At the same time, we all know that a speech is not a plan, and Congress is going to need to know a lot more about the initiative if we are going to evaluate its viability. Unfortunately, the initial explanations have raised more questions than they have answered.

As you know, last month when I asked the President's science advisor and the NASA Administrator what the President was told about the cost of this initiative, I couldn't get a clear answer. I hope that we will get one soon, and that it will be much more clear.

However, "affordability" is about more than just how much it will cost to return the U.S. astronauts to the Moon. "Affordability" also has to do with the impact made to the rest of NASA's program in order to fund the President's plan. In that regard, the cuts, the deferrals, the cancellations that will be made over the next five years to the space launch, space science, Earth science, and biological and physical research activities have already been publicized. What has not gotten much attention is the impact on the non-exploration parts of NASA's budget over the next decade and a half. In fact, in order to fund the exploration initiative, NASA's plan assumes that Earth science, aeronautics, basic biological and physical research, space science research on Sun-Earth connections, space science research on the structure and evolution of the universe, space communications, and education, as well as their associated infrastructure requirements will all be lumped into a single funding pot that will be best—will be, at best, a flat and, more likely, shrinking in purchasing power between now and 2020. That seems to me to be neither a wise nor realistic approach.

So Mr. Chairman, I support the goal of exploring our solar system, however, until I am convinced that the President's plan to

achieve that goal is credible and responsible, I am not prepared to give that plan my support. I think NASA has a lot of work ahead of it if it is going—if it intends to develop a plan that can garner national consensus behind it. And I hope that our witnesses will help identify some of the issues that we need to address.

Once again, I welcome our witnesses today, and look forward to your very important testimony.

[The prepared statement of Mr. Gordon follows:]

PREPARED STATEMENT OF REPRESENTATIVE BART GORDON

Good morning. I want to welcome the witnesses to today's hearing. There are many important issues associated with the President's space exploration initiative, and I look forward to hearing your perspectives.

I come to this hearing as one who believes that it is important for the U.S. civil space program to have challenging long-term goals. Thus, I welcomed the President's January 14th speech announcing some specific exploration goals, including a return to the Moon and eventual human missions to Mars.

At the same time, we all know that a speech is not a plan. Congress is going to need to know a lot more about the initiative if we are to evaluate its viability. Unfortunately, the initial explanations have raised more questions than they have answered.

As you know, last month when I asked the President's science advisor and the NASA Administrator what the President was told about the cost of his initiative, I couldn't get a clear answer. I hope that we get one before too much longer.

However "affordability" is about more than just how much it will cost to return U.S. astronauts to the Moon. "Affordability" also has to do with the impacts made to the rest of NASA's programs in order to fund the President's plan. In that regard, the cuts, deferrals, and cancellations that will be made over the next five years to the space launch, space science, Earth science, and biological and physical research activities have already been publicized. What has not gotten much attention is the impact on the non-Exploration parts of NASA's budget over the next *decade and a half.* In fact, in order to fund the exploration initiative, NASA's plan assumes that:

- Earth Science,
- Aeronautics,
- Basic biological and physical research,
- Space science research on Sun-Earth Connections,
- Space science research on the structure and evolution of the universe,
- Space communications, and
- Education,
- As well as their associated infrastructure requirements. . .

. . .will all be lumped into a single funding pot [the Aeronautics and Other Science category] that will at best be flat and more likely be shrinking in purchasing power between now and 2020. That seems to me to be neither a *wise* nor a *realistic* approach.

Mr. Chairman, I support the goal of exploring our solar system. However, until I am convinced that the President's plan to achieve that goal is credible and responsible, I am not prepared to give that plan my support. I think NASA has a lot of work ahead of it if it intends to develop a plan that can garner a national consensus behind it, and I hope that our witnesses will help identify some of the issues that need to be addressed.

Chairman BOEHLERT. Thank you very much, Mr. Gordon.

Our panel today consists of: Mr. Norman Augustine, former Chief Executive Office of Lockheed Martin, Chair, Advisory Committee on the Future of the U.S. Space Program; Dr. Michael Griffin, President, In-Q-Tel, former Chief Engineer, NASA, former Associate Administrator, Exploration Systems at NASA; Dr. Donna Shirley, Director, Science Fiction Museum, former Manager, Jet Propulsion Laboratory's Mars Program, former Assistant Dean, University of Oklahoma Aerospace Mechanical Engineering De-

partment; Dr. Larry Young, Apollo Program Professor, Massachusetts Institute of Technology, founding Director of the National Space Biomedical Research Institute; and Dr. Lennard Fisk, Chair, Space Studies Board, National Academy of Sciences, Chair, Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan, former Associate Administrator, Space Science and Applications, NASA.

As our audience, and certainly this—the Members up here realize, this is a very distinguished panel, and I thank all of you for serving as resources to this committee. Your minds are fertile ground to be attacked, and we look forward to hearing from you, and, more importantly, we look forward to a healthy and productive exchange.

Mr. Augustine, you are up first.

STATEMENT OF MR. NORMAN R. AUGUSTINE, FORMER CHIEF EXECUTIVE OFFICER, LOCKHEED MARTIN; CHAIR, ADVISORY COMMITTEE ON THE FUTURE OF THE U.S. SPACE PROGRAM

Mr. AUGUSTINE. Well, good morning, Mr. Chairman, and Members of the Committee. And thank you for the invitation to appear before you today. With your permission, I would like to submit a formal statement for the record.

Chairman BOEHLERT. Without objection, the formal statements of all of the witnesses will appear in their entirety. We would ask that you summarize it. Don't get nervous if the red light comes on, Mr. Augustine. What you have to say is too important to be deterred by a red light, and the same holds true for the other panel members. But the shorter the initial presentation, the more opportunity we have for questions.

Mr. AUGUSTINE. Well, before beginning, I probably should, in the spirit of full disclosure of possible conflicts of interest, call to your attention that I am a retiree and a board member of Lockheed Martin Corporation, former President of the American Institute of Aeronautics and Astronautics, a former director of The Planetary Society, and a former chairman of the Aerospace Industry Association.

I—with that said, I have been asked to address the findings to the Committee on the Future of the U.S. Space Program, a committee that was convened 14 years ago by then-President Bush. I have also been asked to share with you my personal thoughts on several specific issues you have raised.

The committee which I chaired in about 1990 found a NASA that was overextended in terms of funding demands of the programs it was undertaking as compared to the funding that was available. The Space Shuttle and the Space Station were, and are today, major consumers of the NASA budget, leaving relatively limited room for other initiatives.

We concluded that America's space program should be a balanced program, involving both humans in space and the use of robotic spacecraft. We observed that science should be given first priority, since science is the basis of new knowledge and thereby also forms the underpinnings of technological progress as well.

We concluded the space transportation was, and I might note is, the primary impediment to a continuing healthy space program. It was concluded that we should not use humans in space as “truck drivers.” Rather, we should limit their roles to instances where humans in situ can, in fact, make a difference. We observed reluctantly, but explicitly, that it was not a matter of if we would lose another Space Shuttle, but only a matter of when. This unfortunate conclusion was based on our belief that the reliability estimates, which were then being attributed to the Shuttle, were grossly optimistic. We predicted that such a loss would probably occur in the next several years. And we went on to note that if America does not have the will to endure occasional losses, having taken all reasonable steps to avoid them, we should reconsider whether our nation belongs in space at all.

Finally, we concluded that a human trip to Mars is the correct long-term goal of America’s space program, using the Moon as a stepping stone to achieve that goal.

That summarizes some of the findings of our commission. Many of the observations are, perhaps, relevant today. I would like now to turn to my own perspective and address the specific questions that you have asked. First, I continue to believe that a human mission to Mars is the proper long-term objective, and should be approached in a step-wise fashion: first the Space Station, then the Moon, and then Mars. There will be those who will say of a manned lunar mission “been there, done that,” but there are good engineering and programmatic reasons for this sequential approach.

While there are technical challenges to be met, especially in the fields of propulsion, electric power generation, and human factors, by far, the greatest challenge that we will face will be to provide adequate funding and to do so over an extended period of time. It is ironic that this should be the case, but far and away, the greatest risk that we could create would be to undertake a complex mission without adequate funding, including reserves, in terms of money, time, and technical approaches. That is why our committee originally proposed a “go-as-you-pay” approach to a Mars program.

With regard to the respective roles of humans and robots, I believe robots are best suited for very high-risk undertakings, very long duration, remote missions, and functions which require minimal adaptability, such as monitoring and reporting. In contrast, humans would be best suited for missions that involve exploration, construction, and repair.

Looking at the priority of a Mars mission in the grand scheme of things, I don’t think that such a mission can be justified solely on the basis of technological and economic benefits. I believe that one must include intangibles, but very real, benefits as well.

The science programs conducted by the NIH and NSF have seen significant growth, although I would note that the hard sciences, physics, chemistry, and their partners, mathematics and engineering, have been neglected. Do I believe that going to Mars is more important than, say, cancer research? Clearly, the answer is no. But do I believe that America, which spends large sums on Hollywood movies, video games, rock concerts, football players, and yes, even golf courses, cannot afford to explore the solar system with

humans? The answer is, again, a resounding no. It is noteworthy that few pursuits seem to attract the interest of America's youth towards science and technology as does the intrigue of exploring space. This is a non-trivial consideration in our world wherein our standard of living increasingly depends on our preeminence in science and technology, yet a world in which the United States graduates a declining number of engineers virtually every year: 58,000 last year as compared with India's 80,000, Japan's 200,000, and China's 800,000.

I would thus conclude—close by observing simply that one day humans will stand on Mars, and the only questions are when and who? The first Martian might well be in the fourth grade somewhere right now. Hopefully it is somewhere in the United States.

Thank you very much.

[The prepared statement of Mr. Augustine follows:]

PREPARED STATEMENT OF NORMAN R. AUGUSTINE

Mr. Chairman and Members of the Committee, thank you for the invitation to appear before you today. I am pleased that you are taking this opportunity to examine America's space program and hope that a plan can be created which will endure over time and in which all Americans can take pride.

Before making my statement I should, in the spirit of full disclosure, call to your attention that I am a retiree and Board Member of the Lockheed Martin Corporation, a former President of the American Institute of Aeronautics and Astronautics, a former director of The Planetary Society and a former chairman of the Aerospace Industry Association.

I have been asked to address the findings of the Committee on the Future of the U.S. Space Program, a committee which was established approximately fourteen years ago by then-President Bush. I will briefly summarize what I believe were some of our more significant findings and recommendations and, as you have requested, close with a few brief observations of my own.

It goes without saying that a great deal has changed since the commission which I chaired conducted its work. Today there is no Soviet Union dedicating substantial resources to maintain its own dynamic space program—and thereby providing a competitive impetus to America's space program. In fact, rather than the Soviets and the U.S. being adversaries in space, the company I recently had the privilege of serving is now a *partner* in launching commercial spacecraft with those same Soviet enterprises that conducted the USSR space program of an earlier era—a notion that would have been unimaginable during the period preceding our committee's deliberations.

And there have been other significant changes which have impacted America's space program during the period which has intervened. For example,

- China is emerging as a major space participant, having recently taken particularly significant steps toward full membership in the space community.
- The United States has not realized the ten percent annual growth in the NASA budget that was forecast by virtually all senior officials in both the Executive Branch and the Congress at the time our commission commenced its work. In fact, NASA's budget, although still significant, has diminished in real terms.
- The commercial space business, (constructing and launching spacecraft) which seemed to hold such great promise a decade ago has largely been reduced to a commodity market and as such has, from an economic standpoint at least, been a disappointment.
- America's space industrial base has shrunk from a number of relatively healthy aerospace companies to a very few firms still maintaining strong space credentials. . .this being largely a consequence of the restructuring of the aerospace industry which occurred when defense spending dropped precipitously following the end of the Cold War.
- And there still seems to be no broad consensus as to what America's long-term space program should comprise.

On the other hand, a great deal has *not* changed. For example,

- Today we meet, as did our committee, in the wake of a failure of the Space Shuttle. . .in our case, the *Challenger.*
- There continues to be strong grassroots support for a space program, however, the transformation of that interest into budgetary measures has not been evident.
- There remain severe competing and legitimate pressures for federal funds. . .with the need to counter terrorism supplanting certain of the demands of the Cold War.
- The number of U.S. citizens studying engineering has continued to decline, even in the midst of the greatest technological explosion in history—an explosion which is growing our economy and modifying our lifestyle at a pace never before witnessed. Meanwhile, the scientific and technological capacities of many other nations are increasing markedly.
- America's K–12 educational system remains *in extremis,* especially in the areas of science and technology—disciplines where space activity seems to be one of the few pursuits that truly inspires many of our young people.
- There remains continuing concern over the apparent loss of some of NASA's innovativeness, management acumen and systems engineering skill. At the same time, NASA, without question, remains the finest space organization in the world, producing remarkable accomplishments on a continuing basis and doing so openly and publicly for all to observe. . .for better or for worse. Nonetheless, few would confuse the NASA of today with the NASA of the Apollo era.

  Unfortunately, much of the public, and, of even greater concern, some at NASA, seem to take for granted these incredible achievements. Dan Goldin, when he was serving as Administrator of NASA, shared with me an incident concerning a citizen who had complained to him about NASA spending substantial sums of money on meteorological satellites, asking, "Why do we need meteorological satellites? We have the weather channel."

I would like now to turn to some of our commission's findings and recommendations. They are, I believe, surprisingly relevant today, even though well over a decade has passed since they were first stated. I will cite thirteen of the more significant of these findings and will address each only very briefly in deference to the time available.

- First, we found a NASA which was badly over-committed in terms of the funding demands of the programs it was undertaking as compared with the funding which was available. The Space Shuttle and the Space Station were major consumers of that budget, leaving little room for other initiatives while making smaller projects highly vulnerable to the consequences of cost-growth in these two major programs. A primary concern was the lack of adequate reserves in terms of time, schedule and technological approaches—a condition which exacerbated the potential impact of risks already inherent in NASA's challenging endeavors.
- Second, in the post-Apollo period there seemed to be a lack of a broadly embraced national goal for our space program. . .some would even say that America was lost in space. At the same time, our commission believed that it was inappropriate to set a firm date to achieve a specific major space goal given the then-prevailing budgetary circumstances. Rather, we felt it was important to invest first in building a solid technological foundation for whatever was to be America's long-term program and thereafter to conduct that program on what we called a "go-as-you-pay" basis. . .an approach that was recognized as differing markedly from the highly successful strategy adopted by President Kennedy for the Apollo program. Our recommendation was merely a reflection of the fact that times had changed and that large sums of additional near-term money to underpin a major space venture, such as a human Mars program, were unlikely to be forthcoming.
- Third, we concluded that America's space program should be a *balanced* program, involving both humans in space and the use of robotic spacecraft. Although there were those who exclusively advocated robotic systems, it was our belief that public support for the overall space program would diminish rapidly were the Nation to adopt a purely unmanned approach to space exploration. As we pointed out in our report, the difference between Hillary reaching the summit of Mt. Everest and simply lobbing a rocket carrying an electronic package to the mountain's crest is immense in terms of the inspiration humankind derives from the feat.

- Fourth, we concluded that science should be the first priority of our space program. . .since science is the basis of new knowledge and thereby forms the underpinning of technological progress.
- Fifth, there should be a mission *to* the planet Earth as well as a mission *from* the planet Earth, the former focusing on the Earth's biosphere and the need to protect our planet from harmful activities which take place here on Earth.
- Sixth, space transportation was, and I might note *is,* the primary impediment to a continuing healthy space program. It was concluded that we should not use humans in space merely as "truck drivers". . .rather, we should limit their role to instances where humans *insitu* can in fact make a difference. In short, we urgently needed to mitigate our dependence on the Space Shuttle for logistical missions.
- Seventh, very high priority was placed on developing a new unmanned (but potentially man-ratable) launch vehicle with a relatively heavy lift capability. In this regard, we recommended, as an economic move, that no additional Shuttles be built.
- Eighth, the operation of the Space Shuttle should not be viewed, as had increasingly been the case in the late 1980s, as being somewhat analogous to running an airline. The Shuttle was, and is, best characterized as an advanced development program operating in a very unforgiving environment.
- Ninth, we noted quite explicitly that it was not a matter of *if* we would lose another Space Shuttle but only a matter of *when.* This unfortunate conclusion was based on our belief that the reliability estimates which were then being attributed to the Shuttle were grossly optimistic. In fact, we predicted that such a loss would probably occur "in the next several years" and we went on to note that if America does not have the will to endure occasional losses—having taken all reasonable steps to try to avoid them—we should then reconsider whether our nation belongs in space at all. Space is inherently a dangerous and risky place. . .one which is altogether unforgiving of human failings. No one realizes this more than the astronauts who fly our machines into space.
- Tenth, the Space Station program needed to be restructured to place it on a more conservative schedule and more realistic financial basis, importantly including the provision of adequate reserves.
- Eleventh, there was a need to proceed with dispatch in the development of some form of a space rescue vehicle. . .a vehicle which could perhaps perform other important missions as well.
- Twelfth, we concluded that a human trip to Mars is the correct long-term goal for America's space program, using the Moon as a stepping-stone along the way. Other possible missions were considered, including establishing a permanent station at the neutral gravity point in the Earth-Moon system. This would in fact produce a useful way-station for exploration of deeper space, however it provides an altogether uninteresting locale for most other forms of scientific enterprise. Alternatively, one could increase the effort focused on Earth-orbiting spacecraft, however, the Space Station seemed to be handling that goal very adequately and was itself likely to suffer from the law of diminishing returns in the longer-term. Missions to Phobos and Deimos appeared exciting, but could be accomplished as a part of a Mars project. Missions to other space objects would seem to be candidates for the more distant future. Thus, a return to the Moon followed by a Mars mission seemed to us to be the correct long-term goal for America's space program.
- Thirteenth, and lastly, NASA's management structure, engineering approach and overhead costs needed to be streamlined. As with many mature organizations, the drive toward self-perpetuation seemed to be overtaking enthusiasm for innovation. The various Centers were often engaged in non-constructive competition with one another, seemingly united only in their not-infrequent skirmishes with NASA headquarters.

That, then, summarizes the principal findings of our commission of fourteen years ago. As I have noted, most of these observations seem quite relevant even today.

Now, with your permission, I would like to conclude my remarks with four very brief observations not on behalf of our commission but on my own stead.

First, if America is to have a robust space program it is critical that we build a national consensus as to what that program should comprise. If, for example, we are to pursue an objective that requires twenty years to achieve, that then implies we must have the sustained support of five consecutive presidential administrations,

ten consecutive Congresses and twenty consecutive federal budgets—a feat the difficulty of which seems to eclipse any technological challenge space exploration may engender. This consideration argues for a major space undertaking that could be accomplished in step-wise milestones, each contributing to a uniting long-term goal. Such an approach has the added advantage that it reduces the risk associated with individual steps. It is this consideration which justifies a mission to Mars with an initial step to the Moon—as philosophically opposed to a return to the Moon with a potential visit to Mars.

Second, I believe that the exploration of space with humans offers many scientific, technological and economic benefits. But these tangible benefits are, in my opinion, not sufficient *in themselves* to justify the cost of the undertaking. To do the latter one must assign value to *intangibles,* intangibles such as the excitement of exploring the unknown; of creating new knowledge; of stimulating science and engineering education; of undertaking challenging and inspiring goals; and of demonstrating to the world what America can do when it puts its mind to a task. Critics will of course suggest that we cannot afford such "luxuries" in a time of great and legitimate demands to address compelling earthly problems—but if they are correct, one must also ask whether we can then afford football stadiums, Hollywood entertainment, golf courses and a thousand other well accepted pursuits.

Third, and this is extremely important, it would be a grave mistake to try to pursue a space program "on the cheap." To do so is in my opinion an invitation to disaster. There is a tendency in any "can-do" organization to believe that it can operate with almost any budget that is made available. The fact is that trying to do so is a mistake—particularly when safety is a major consideration. I am not arguing for profligacy; rather, I am simply pointing out that space activity is expensive and that it is difficult. One might even say that it is rocket science!

Significant funding will still be required for many years to support the operation of the Space Station and Space Shuttle. The NASA infrastructure itself absorbs substantial funds, as does the very important NASA research program. And there is always the problem that technology advances so rapidly that any project proceeding at too leisurely a pace will find itself constantly undertaking redesigns due to the obsolescence of the components it incorporates. . .sort of a never-ending "do-loop."

And finally, as a general observation, I would like to strongly affiliate myself with the President's recently announced plan to send humans to Mars and to do so via a lunar way-station. One-day humans *will* stand on Mars. The only question is *when*. . .and *who.* The first Martian may well be in the fourth grade right now. Hopefully, somewhere in the United States.

Thank you.

Biography for Norman R. Augustine

NORMAN R. AUGUSTINE was raised in Colorado and attended Princeton University where he graduated with a BSE in Aeronautical Engineering, magna cum laude, an MSE and was elected to Phi Beta Kappa, Tau Beta Pi and Sigma Xi.

In 1958 he joined the Douglas Aircraft Company in California where he held titles of Program Manager and Chief Engineer. Beginning in 1965, he served in the Pentagon in the Office of the Secretary of Defense as an Assistant Director of Defense Research and Engineering. Joining the LTV Missiles and Space Company in 1970, he served as Vice President, Advanced Programs and Marketing. In 1973 he returned to government as Assistant Secretary of the Army and in 1975 as Under Secretary of the Army and later as Acting Secretary of the Army. Joining Martin Marietta Corporation in 1977, he served as Chairman and CEO from 1988 and 1987, respectively, until 1995, having previously been President and Chief Operating Officer. He served as President of Lockheed Martin Corporation upon the formation of that company in 1995, and became its Chief Executive Officer on January 1, 1996, and later Chairman. Retiring as an employee of Lockheed Martin in August, 1997, he joined the faculty of the Princeton University School of Engineering and Applied Science where he served as Lecturer with the Rank of Professor until July, 1999.

Mr. Augustine served as Chairman and Principal Officer of the American Red Cross for nine years and as Chairman of the National Academy of Engineering, the Association of the United States Army, the Aerospace Industry Association, and the Defense Science Board. He is a former President of the American Institute of Aeronautics and Astronautics and the Boy Scouts of America. He is currently a member of the Board of Directors of ConocoPhillips, Black & Decker, Procter & Gamble and Lockheed Martin and was founding chairman of In-Q-Tel. He is a member of the Board of Trustees of Colonial Williamsburg and Johns Hopkins and a former member of the Board of Trustees of Princeton and MIT. He is a member of the President's Council of Advisors on Science and Technology and the Department of Home-

land Security Advisory Board and was a member of the Hart/Rudman Commission on National Security.

Mr. Augustine has been presented the National Medal of Technology by the President of the United States and has five times been awarded the Department of Defense's highest civilian decoration, the Distinguished Service Medal. He is co-author of *The Defense Revolution* and *Shakespeare In Charge* and author of *Augustine's Laws* and *Augustine's Travels.* He holds eighteen honorary degrees and was selected by Who's Who in America and the Library of Congress as one of the Fifty Great Americans on the occasion of Who's Who's fiftieth anniversary. He has traveled in nearly 100 countries and stood on both the North and South Poles.

Chairman BOEHLERT. Thank you very much.

Dr. Griffin.

STATEMENT OF DR. MICHAEL D. GRIFFIN, PRESIDENT, IN-Q-TEL; FORMER CHIEF ENGINEER, NASA; FORMER ASSOCIATE ADMINISTRATOR, EXPLORATION SYSTEMS, NASA

Dr. GRIFFIN. Thank you for inviting me to appear before the Committee to discuss our nation's future in human space flight. We are at a seminal moment in discussing that future, a moment which has followed inevitably from the tragic loss of Space Shuttle *Columbia.* If there is a single fundamental point to be found in the report of the *Columbia* Accident Investigation Board beyond identifying the technical and cultural causes of the mishap, it is that the Nation's human space flight program has, for decades, lacked a unifying theme or purpose worthy of its cost and risk. I believe it is now widely accepted that circling endlessly in low-Earth orbit does not qualify as such a purpose.

The United States will not abandon manned space flight. Not to have the capability to fly humans in space when other nations do, and more will follow, is simply unacceptable for a great nation. But if we are not to abandon human space flight, and if our goals must reach beyond the Space Station, the geography of the solar system dictates the path. Only the Moon, Mars, and the nearer asteroids are within reach of the next few generations, and that is where the President's vision has directed us. It is the right path.

But there are many potential roadblocks along the path. One of these is the cost of the vision and the allied question of whether there will or can be sufficient funding to support it. In my opinion, the issue is not whether enough money has been allocated to the President's initiative, but is, rather, why are we expecting so little for the money which has been allocated? Even worse, our expectations seem to decrease as time goes on. Budget estimates for the 2005 to 2020 period show an aggregate allocation of some $50 billion to $55 billion to rebuild a basic Apollo-like capability, NASA's words, by 2020. This estimate is considerably higher than that derived from the most thorough prior study of an Apollo-like return to the Moon, the First Lunar Outpost, which occupied many of us from 1991 through 1993. Top level cost estimates were about $30 billion in 2003 dollars, 60 percent of today's allocation. This is difficult to understand.

For advocates of space flight, including myself, more money is always better, but I would submit that our first order of business is to examine our culture, the aerospace culture, to understand why we believe it costs so very much more to operate in space than to perform other human activities of similar complexity. It is commonly supposed that there are great technical or physiological hur-

dles standing between us and fulfillment of the President's vision. Indeed, some of the architectures presented seem intended to stun the observer with sheer complexity. I don't recommend that we pursue those.

In the early years, it will be best to proceed directly to the Moon and directly to Mars. If this is done, there is no fundamentally new technology required to enable a human return to the Moon, the establishment of a lunar base, or the first voyages to Mars. It is true that technical and physiological challenges do exist. Exploration missions will not be accomplished without risk, but while worthy of our attention, none of these is so daunting that we should stay home.

If the International Space Station is to be completed, there are specific tasks associated with going to Mars for which it can be useful, including biomedical experiments, crew training, or as a test bed for the space qualification of systems and vehicles. In a word, ISS will help—is helping us to learn to live and work in space.

But the more important question is whether the value to be obtained from ISS is worth the money yet to be invested in its completion. The Nation plans to allocate $32 billion to ISS through 2016 and another $28 billion to Shuttle operations, which support it, through 2011. This total of $60 billion is significantly higher than NASA's current allocation for human lunar return. It is beyond reason to believe that ISS can fulfill any set of objectives for space exploration that would be worth the $60 billion remaining to be invested in the program. Moreover, given recent—given present budget constraints, we return to the Moon in 2020, thus accomplishing in 16 years what it required eight years to achieve the first time. This is not because the task is more difficult or because we are so much less capable than our predecessors, but because we do not actually begin work on it until 2011. I do not need to point out to this body the political pitfalls endemic to such a plan.

I, and others, have elsewhere advocated that the Shuttle be returned to flight and the ISS brought to completion if only because the program's two decade advocacy by the United States and our commitment to our international partners should not be abandoned. But if there is no additional money to be allocated, this position must be questioned. It is worth asking whether our international partners might judge it similarly.

With that, Mr. Chairman, I stand ready to answer your questions and your Committee's. Thank you.

[The prepared statement of Dr. Griffin follows:]

PREPARED STATEMENT OF MICHAEL D. GRIFFIN

Abstract

President Bush's recently announced vision for a renew program of human space exploration is examined. Budgetary requirements are considered, and specific technology development recommendations are made. Relevant policy questions are posed.

Mr. Chairman:

Thank you for inviting me to appear before the Committee to discuss our nation's future in human space flight. We are a seminal moment in discussing that future, a moment which has followed inevitably from the tragic loss of Space Shuttle *Columbia,* little more than a year ago. If there is a single fundamental point to be found in the report of the *Columbia* Accident Investigation Board—beyond identi-

fying the technical and cultural causes of the mishap—it is that the Nation's human space flight program has for decades lacked a unifying theme or purpose worthy of the cost and risk endemic to the enterprise. I believe it is now widely accepted that circling endlessly in low Earth orbit does not qualify as such a theme. The United States will not abandon manned space flight. Not to have the capability to fly humans in space, when other nations do and more will follow, is simply unacceptable for a great nation. But if we are not to abandon human space flight, and if our goals much reach beyond the Space Station, the geography of the solar system dictates the path. Of the possible venues of human activity beyond LEO, only the Moon, Mars, and the nearer asteroids are within reach of the next few generations. And that is where the President's vision has directed us. It is the right path. With the remainder of this statement, I will direct my efforts to responding to the questions contained in the Committee's invitation to appear at this hearing.

Does the estimated spending through 2020 seem adequate to carry out the President's initiative? Which elements of the President's initiative seem most likely to cost more money or take more time than is currently allotted to them?

In my opinion, the issue is not whether enough money has been allocated to the President's proposed initiative, but is rather this: Why we are expecting so little for the money which has been allocated?

NASA budget estimates for the 2005–2020 period, culminating in the first manned lunar return mission by the latter year, show an aggregate allocation of some $50–55B (including the Crew Exploration Vehicle) to rebuild a basic "Apollo-like" capability. A top-level cost breakdown shows the following line items:

Item	FY03 $B
Crew Exploration Vehicle	$15
Lunar Lander	$10-12
Launch Vehicle	$13-16
Operations	$9-10
Other	$2
Total	$50-55

This amount should be sufficient for the task as presently understood. In fact, it is possible to argue credibly that the estimate is somewhat high.

To address only one item, numerous careful studies have been performed to estimate the cost of developing a 100 metric-ton-class launch vehicle based on the use of Shuttle-derived components. Such estimates consistently show non-recurring engineering development to be in the $3–5B range, depending on the option considered. If other estimates show the likely development cost of a clean-sheet-of-paper design having the same payload capability to be in the $13–16B range, then we should seriously question whether it makes sense to pursue such an option.

The most thorough study of an "Apollo-like" return to the Moon previously conducted by NASA was the "First Lunar Outpost" (FLO) effort, which occupied many of us from 1991–93. FLO was intended not as a definitive or final architecture for lunar return, but rather as a working baseline, to establish a credible point of departure for further efforts, which were unfortunately terminated at the outset of the Clinton Administration. The FLO architecture offered some improvement as compared to Apollo capability, but not so much as to be beyond our credible experience base at that time. Top level FLO cost estimates were:

Item	FY92 $B
Crew Vehicle Development & 1st Unit	$7.4
Surface Habitat and Systems	$2
Launch Vehicle Development & 3 Vehicles	$12.6
Unmanned Lander & Cargo Production (2 Units)	$3
Total	$25

The FLO costs must be inflated by about 30 percent to account for the difference between 1992 and 2003 dollars, resulting in an estimate of about $33B for an initial lunar return. Also, the FLO studies assumed that the then-planned International Space Station habitat module would be available (with some modifications) for use on the lunar surface. Substantial development resources would be required to restore such a capability at this point, were it to be included in a lunar return mis-

sion. However, because a surface habitat is not included in the current planning estimate, it should be deleted from the comparison, yielding a 2003 FLO cost estimate of about $30B, no more than 60 percent of NASA's current assessment.

Considerable study was devoted to FLO cost and feasibility analysis, in some cases by the same NASA personnel as are engaged in the present effort. It is difficult to understand why there should exist such a discrepancy between today's estimates and those of a decade ago. One can certainly understand that any estimate derived from a design study will lack the credibility of a completed development program. But it is difficult to understand why two estimates for very similar development programs would differ so greatly.

Additional perspective can be gained by noting that the cost of the entire Apollo program was about $130B in today's dollars. This included massive technology and infrastructure development, as well as the operational cost of eleven manned missions, including six lunar landings. It does not seem reasonable that 40 percent or more of this figure should be required to execute a single mission of a similar class today.

For advocates of space flight, including myself, more money is always better, and is certainly preferable to less money! But I would submit that our first order of business is to examine our culture, the aerospace culture, and ourselves, to understand why we believe it costs so very much more to operate in space than to perform almost any other human activity.

NASA's spending plan through 2020 does not explicitly include any activity in support of manned missions to Mars, or indeed any exploration activity beyond early lunar return. I therefore cannot comment on the reasonableness of such plans at this time. This is regrettable, because the goal of pushing on to Mars should, in part, drive program requirements even while planning to return to the Moon.

What are the greatest technological hurdles the President's initiative must clear to be successful? To what extent must resolving some technological issues await further fundamental research? For example, how much work on a spacecraft for a Mars mission can be done before more is known about the effect on humans of spending long periods of time in space? How much work can be done before new propulsion technologies are developed?

The question of what technological hurdles stand between us and the fulfillment of the President's vision depends, to a very great extent, on the mission architecture(s) which are selected to achieve that vision. In a very real sense, there is essentially no fundamental new technology required to enable human return to the Moon, the establishment of a lunar base, or the first voyages to Mars.

It is true that technical challenges exist, and that there are numerous systems needed to implement the vision that are not currently in production. Among the specific engineering development tasks needing to be performed are:

- NASA should initiate development of a heavy lift launch vehicle having a payload capacity of at least 100 metric tons to low Earth orbit (LEO). Such a vehicle is the single most important physical asset enabling human exploration of the solar system. The use of shuttle-derived systems offers what is quite likely to be the most cost-effective near-term approach.
- Much cargo (including humans) does *not* need to be launched in very large packages. We desperately need much more cost effective Earth-to-LEO transportation for payloads in the size range from a few thousand to a few tens of thousands of pounds. In my judgment, this is our most pressing need, for it controls a major portion of the cost of everything else that we do in space. Yet, no active U.S. government program of which I am aware has this as its goal. Again, shuttle-derived systems, particularly emphasizing use of the RSRB, may offer a useful approach.
- New propulsion systems are unnecessary. We can certainly return to the Moon or go to Mars using existing chemical propulsion systems. Looking ahead, development of nuclear propulsion should be re-initiated to allow more efficient travel beyond cislunar space, but such systems are not altogether new. The NERVA (nuclear engine for rocket vehicle applications) program produced a working nuclear upper-stage engine and demonstrated excellent performance in extensive ground tests, before regrettably being canceled in 1973.
- Compact space qualified nuclear power systems are required for extended human presence on the Moon and Mars.
- The efficient establishment of permanent human bases on the Moon, Mars, and certain asteroids requires the use of *in situ* resources to minimize the

amount of material and equipment which must be brought from Earth. The technology for such exploitation has yet to be fully developed, though promising experiments have been conducted.

- Space and planetary surface habitat and suit technology is at present insufficient for the needs of an extended program of human space exploration. Improvements in suit technology are of the highest priority.

Physiological challenges also exist. We have considerable experience in the microgravity environment, and some practical and effective countermeasures have shown promise in minimizing bone loss, though more work is clearly needed. However, in the near-term it is very clear from the existing base of human space flight experience that microgravity effects are not an impediment to lunar return or to expeditions to Mars. And, as a practical matter, it is always possible to design our spaceships to supply artificial gravity by spinning them to generate the necessary centrifugal force.

The long-term human adaptation to life on other planetary surfaces is another matter. We have at present no clear understanding of how the human organism will respond to fractional gravitational environments such as will be experienced on the Moon and Mars.

Overall, however, the most difficult physiological issue is likely to be that of cosmic heavy ion radiation. The human effects of and countermeasures for heavy ion radiation, encountered in deep space but not in the LEO environment of the ISS, have received little attention thus far.

These are the essential technical and physiological challenges as I see them. Exploration missions will not be accomplished without human risk. While certainly worthy of our attention, however, none of these is so daunting that we should stay home.

However, it is always possible to make the problem more difficult. ,Some of the space flight architectures that have been advocated seem intended to stun the observer with sheer complexity. If we are planning to defer return to the Moon until we have established L1 Gateways, solar electric propulsion systems to ferry liquid oxygen up from low-Earth orbit, and so on, then it may indeed be possible to spend a very large amount of time and money on technology development. I do not recommend that we pursue such paths.

Are the International Space Station and the Moon the most appropriate stepping stones for human space exploration if the ultimate objective is a human landing on Mars? What would be the advantages and disadvantages of a program that was targeted instead directly on sending a human to Mars?

Given that ISS is to be completed, there are specific tasks associated with going to Mars for which it can be useful. Certainly, it can be useful in carrying out controlled experiments to study the effects of microgravity, and proposed countermeasures, on humans, provided of course that it is equipped with a habitat module or modules. It can serve as an aid to crew training, acclimating a proposed Mars crew, or extended-duration lunar crew, to the regimen of space flight in company with each other. It can serve as a testbed for the space qualification of specific systems, or even vehicles, prior to their use on extended voyages far from home. In a word, ISS can help us learn to live and work in space.

But the more important question is whether the return to be obtained from the use of ISS to support exploration objectives is worth the money yet to be invested in its completion. The Nation, through the NASA budget, plans to allocate $32B to ISS (including ISS transport) through 2016, and another $28B to Shuttle operations through 2011. This total of $60B is significantly higher than NASA's current allocation for human lunar return. It is beyond reason to believe that ISS can help to fulfill any objective, or set of objectives, for space exploration that would be worth the $60B remaining to be invested in the program.

Equally important is the delay in pursuing the President's vision. Respecting present budget constraints, we return to the Moon in 2020, thus accomplishing in 16 years what it required eight years to achieve in the 1960s. This is not because the task is so much more difficult, or because we are today so much less capable than our predecessors, but because we do not actually begin work on the task until 2011. I do not need to point out to this body the political pitfalls endemic to such a plan.

I, and others, have elsewhere advocated that the Shuttle should be returned to flight and the ISS brought to completion, if only because the program's two-decade advocacy by the United States and commitment to its international partners should not be cavalierly abandoned. But, if there is no additional money to be allocated to

space exploration, this position becomes increasingly difficult to justify. It is worth asking whether our international partners might judge the issue similarly.

With regard to the Moon, I believe the experience to be gained by living on and exploring another planetary surface only a few days away from home will be invaluable to the successful conduct of a future Mars expedition. Certainly such experience is not essential; one can readily envision a Mars expedition architecture which does not employ any further lunar experience as a stepping stone. But because it can be envisioned does not make it wise. I personally consider it an act of technological hubris to proceed directly to Mars, with no human experience beyond Earth orbit having been incurred since 1972. It can be done, and it will be cheaper, but the risk to both the mission goals and to human life will be significantly higher.

If the goal of the United States is solely to mount an expedition to Mars, then I can at least understand, if not credit, the concern that returning to the Moon is a distraction. But if the goal of the United States is to be truly a space-faring nation, then bypassing the Moon is silly.

What questions is it most important for Congress to ask as it evaluates the proposed initiative?

In discussing the President's initiative as it has been put before us, we in the space policy community have spent most of our time debating the cost and technical merit of one approach or the other; whether it makes sense to go to the Moon or not; if so, what to do and how much time to spend there; what new technology is or is not needed, and why, and so on. These are of course interesting questions—but they are not in my opinion the questions which are most relevant for the Congress to ask. Among these more relevant questions might be the following:

- Why does space flight—human or robotic—cost so much more than other comparably complex human activities, and what can be done to remedy the situation?
- Is a serious program of human space exploration sustainable, given the "cost of doing business" presently associated with the enterprise?
- What incentives can be offered to proven and well-established aerospace contractors to devise innovative and cost-effective, yet safe and reliable, approaches to building a new human space flight infrastructure?
- Where and how does NASA intend to engage the entrepreneurial high-tech culture which has made our nation the envy of so many others, in so many areas other than aerospace? What can we do to bring the engine of capitalism to space flight?
- What is the proper role of prizes, or of pay-for-performance contracts, in stimulating and encouraging the high-tech community to devote its attention to aerospace?
- Can or should the Congress establish prizes for specific accomplishments in space flight, independently of NASA?
- What is NASA's proper role in the development of new space systems, beyond setting requirements to be met through competition in industry?
- What is NASA's proper role, as an agency of the U.S. government, in the conduct of future space flight operations?
- If the exploration of new worlds requires technologies and skills beyond those presently available within NASA—and it clearly does—how are the skills of other agencies and laboratories to be used effectively in the service of the larger mission? How will the overall effort be directed?
- Given that we as a nation will spend a certain amount each year on civil space activities, what would Americans prefer to see this money used for? What vision for space exploration excites people enough to cause them to believe that the money they spend on it is well spent? Can a reasonable consensus even be found? How do we know?
- Is the United States interested in leading an international program of space exploration? Which nations might be competitors, and which might be partners? How and in what role do we view our potential partners in the enterprise? What do our potential partners think about this? How do we know?

BIOGRAPHY FOR MICHAEL D. GRIFFIN

Michael D. Griffin is currently President and Chief Operating Officer of In-Q-Tel. On March 29th, he will succeed to his new position as Space Department Head at the Johns Hopkins University Applied Physics Laboratory.

Prior to joining In-Q-Tel, Mike was CEO of the Magellan Systems Division of Orbital Sciences Corporation. He also served as General Manager of Orbital's Space Systems Group and as the company's Executive Vice President/Chief Technical Officer. He has previously served as both the Chief Engineer and the Associate Administrator for Exploration at NASA, and as the Deputy for Technology of the Strategic Defense Initiative Organization.

Before joining SDIO in an executive capacity, Mike played a key role in conceiving and directing several "first of a kind" space tests in support of strategic defense research, development, and flight testing. These included the first space-to-space intercept of a ballistic missile in powered flight, the first broad-spectrum space-borne reconnaissance of targets and decoys in midcourse flight, and the first space-to-ground reconnaissance of ballistic missiles during the boost phase.

Mike holds seven degrees in the fields of Physics, Electrical Engineering, Aerospace Engineering, Civil Engineering, and Business Administration, has been an Adjunct Professor at the George Washington University, the Johns Hopkins University, and the University of Maryland, and is the author of over two dozen technical papers and the textbook *Space Vehicle Design*. He is a recipient of the NASA Exceptional Achievement Medal, the AIAA Space Systems Medal, the DOD Distinguished Public Service Medal, and is a Fellow of the AIAA and the AAS. Mike is a Registered Professional Engineer in Maryland and California, and a Certified Flight Instructor with instrument and multi-engine ratings.

Chairman BOEHLERT. Thank you very much. And I'm sorry for the interruption.

Here is the deal. We will ask Dr. Shirley to present her testimony, and then we will have to pause for approximately 20 minutes while we answer the call of the House. There are a series of three votes, so we will let the clock run out almost on the first vote, dash over there, get two more five-minute votes, which always end up being eight minutes, and then we will come back.

Dr. Shirley.

STATEMENT OF DR. DONNA L. SHIRLEY, DIRECTOR, SCIENCE FICTION MUSEUM; FORMER MANAGER, JET PROPULSION LABORATORY'S MARS PROGRAM; FORMER ASSISTANT DEAN, UNIVERSITY OF OKLAHOMA AEROSPACE MECHANICAL ENGINEERING DEPARTMENT

Dr. SHIRLEY. Good morning. I am Donna Shirley, Director of the Science Fiction Museum and Hall of Fame in Seattle, Washington and formerly Manager of the Mars Exploration Program at JPL. And I worked on the Space Station in the early '80s and a number of studies of human missions to the Moon and Mars. My remarks are my own opinions and do not reflect the views of the Science Fiction Museum.

This morning, I will briefly summarize my answers to the questions.

In my opinion, human space exploration is justified by the natural need of humans to explore. It is wired into our DNA. Judging by the relative number of recent science fiction novels about the Moon, almost none, at least a dozen, Mars is the public's preferred place to go. Humans and robots will be partners in exploration, not competitors. Humans can conduct science at the Moon or Mars but are generally not as effective as robots for this purpose. Robots are extensions of our senses.

The International Space Station can be useful as a facility for evaluating human physiology and psychology to prepare for exploration, but if the goal of exploration is to send humans to Mars, the Moon is a diversion of time and money. There are no lunar resources that are useful for Mars and worth the cost of boosting the

equipment from Earth to exploit. The environments of the Moon and Mars are so different that there is little crossover in surface technology.

The costs of the program are difficult to evaluate, but even the upper-bound projections for 15 or 20 years are less than the Defense budget for a single year. I can't really judge the impact of the program on other NASA missions, because the details are only clear for 2005. However, there are several strategic flaws with the program, including a possibly premature phase-out of the Shuttle and certainly premature focus on a specific exploration approach, which is at least 50 years old and needs to be completely rethought.

NASA continues, as it has for its entire existence, to pursue the approach that Wernher von Braun proposed in Collier's magazine in 1952. This approach can be visualized by watching the movie "2001: A Space Odyssey". The times have changed, and we need to look at new approaches. We need new ideas. NASA's current designs are a rehash of the same concepts we were studying in the 1980s. We need new technologies. For example, the space elevator, which was the subject of Arthur C. Clarke's "Fountains of Paradise" in 1956, appears to be close to being enabled by structures built with carbon nanotubes, and commercial ventures are being undertaken to build one. None of NASA's human exploration studies that I have seen are looking at anything so creative.

There are new economics. Dennis Tito is the vanguard of space tourism, and many companies are vying to put people in orbit, and there is an article on the—in the latest Scientific American, just out, about some of those companies. New launch companies, with their backers, include Scaled Composites, supported by Paul Allen, and John Carmack's Armadillo Aerospace. A new bill to provide regulatory standards has just passed the House of Representatives.

There are new ways of doing business. For instance, NASA has come up with these "challenge" prizes, but what is the process for infusing the results into the program? It is not stated.

There are new international players. China's Shenzhou program has orbited its first taikonaut. The U.S. needs either to compete or cooperate with the Chinese, but the current vision is silent on this.

There is a new culture. As pointed out in the CAIB report, NASA is a bureaucracy shaped by politics. The fundamental nature of the civil service staff centers will make it very difficult to create real change. Converting the center to contract organizations, such as JPL, should be explored.

Unfortunately, the President's vision skips over the need for a process to provide goals for the program. Like most other human programs, it merely states the goals of the Administration and plunges directly into an implementation. This has been shown over and over to be a flawed strategy.

The Committee should urge the Administration to create a process for developing a truly fresh approach to space exploration. Non-NASA, non-government ideas should be involved in the selection of a vision. The process should generate new concepts, bring in new players, consider new approaches and technologies, and fully engage the public to develop a set of goals. This process should drive the definition of a new vision and approaches for human space ex-

ploration and a program to carry them out. This will not be an easy task, because government institutions are not accustomed to such an open process, but the Science Fiction Museum and Hall of Fame would be delighted to participate.

Thank you.

[The prepared statement of Dr. Shirley follows:]

PREPARED STATEMENT OF DONNA L. SHIRLEY

Abstract

In my opinion human space exploration is justified by the natural predilection of humans to explore. Humans could conduct science at the Moon or Mars but are generally not as effective as robots for this purpose. Humans and robots will be partners in exploration. The International Space Station can be useful as a facility for evaluating human physiology and psychology to prepare for exploration. But if the goal of exploration is to send humans to Mars the Moon is of little value in such preparation and, in fact, is a diversion of time and money from the goal. The costs of the program are difficult to evaluate but there appear to be several strategic flaws, including a possibly premature phase-out of the Shuttle and premature focus on a specific approach. There is no real information on which to judge the impact of exploration on other NASA missions. I will make several recommendations for revisiting and improving the vision, specifically to include a wide range of "stakeholders" including private space enterprise and non-traditional technologies.

Testimony

I am Donna Shirley, Director of the Science Fiction Museum and Hall of Fame in Seattle, Washington. I was recently Assistant Dean of Engineering at the University of Oklahoma and before that I retired in 1998 as Manager of the Mars Exploration Program at the Jet Propulsion Laboratory. During my 32-year career at JPL I worked on a number of human exploration missions including participating in the initial design of the Space Station in the early 1980's and in studies of human missions to the Moon and Mars in the 1980's and 1990's. I led two NASA-wide studies in the 1990's, one of which developed a standard process for systems engineering for the Agency[1] and another of which analyzed and recommended improvements to NASA's program and project management processes.

My remarks are my own opinions and do not reflect the views of the Science Fiction Museum. However I would like to speak from the perspective of a person who was inspired by science fiction to pursue an engineering career, and who continues to be inspired by the inventiveness of science fiction writers. I will take a cue from Neil Armstrong, who recently used a science fiction theme to talk about the relative roles of humans and robots in space exploration. The popularity of science fiction teaches us that people are fascinated with the idea of exploration. Studies of history, anthropology and primate behavior teach us that humans have a built-in imperative to seek new terrain, just as the crew of the Starship enterprise "explores strange new worlds". Mr. Armstrong pointed out that an early science fiction play, *Rossum's Universal Robots,* stressed the utility of having robotic laborers to do dangerous, dull or dirty tasks. But science fiction from Buck Rogers to the modern Mars novels like *Red Mars* shows that people also want to explore the cosmos.

In this context I will address the several questions I was asked by the Committee in the context of the President's Vision as summarized in a White House press release.[2]

What are compelling justifications for sending humans into space? Does the President's initiative provide adequate justification for sending humans to the Moon and Mars?

The quick answer is to the second question is "yes." The justification is that the need to explore is "wired into our DNA." Neuroscience has discovered changes in the brains of adolescents related to their propensity for risky adventures.[3] And many people routinely engage in risky behaviors for the thrill of it. Many adults have a desire to go into space and two, Dennis Tito and Mark Shuttleworth, have

[1] SP 6105, NASA Systems Engineering Handbook, June 1995

[2] http://www.spaceref.com/news/viewpr.html?pid=13412, from PRESS RELEASE, Date Released: Wednesday, January 14, 2004, Source: White House, President Bush's Vision for U.S. Space Exploration

[3] "Adolescent Brain Development and Legal Culpability," American Bar Association, Criminal Justice Section, Spring 2003.

paid millions to the Russians for the opportunity to visit the ISS. Studies show that thousands of people may be willing to pay six figures for even a sub-orbital ride.[4]

However, while the justification for human exploration is clear, the justification for the Moon as a destination before Mars is not. If the goal is humans on Mars the Moon is an expensive and time-consuming delay. So the general vision is good, but the feasibility of the proposed implementation is not clear.

The "Moon first" part of the vision is overly specific. There needs to be a process for deciding what should be targets and how to reach them. One of NASA's mistakes is to keep trying to repeat Apollo with Wernher von Braun's 70-year-old vision for human space exploration.

To what extent would scientific research concerning Mars be aided by a human presence on, or in orbit around that planet?

Humans would do science if they went, but should not go just to do science. For example, studies have shown that semi-autonomous rovers on Mars given direction by humans on Earth are far more effective in exploration (in distance and especially dollar for dollar) than rovers "tele-operated" by humans from Mars orbit.[5]

The argument that only humans can do science "in situ" is flawed. The lunar "orange dirt" noticed by Harrison Schmitt[6], first (and last) scientist on the Moon, is used as evidence that robots could never have noticed such a scientifically important find. But the truth is that robots such as Spirit and Opportunity, who are currently on Mars, have a far wider range of senses than a human.[7] Robots merely extend human senses both in distance and wave length. The Mars rovers' instruments can "see" in wavelengths far beyond human sight. Their instruments return data so that scientists on Earth can perceive the Martian surface in ways that humans on Mars (unless they were carrying such instruments) could not.

Are the International Space Station and the Moon the most appropriate stepping-stones for human space exploration if the ultimate objective is a human landing on Mars? What would be the advantages and disadvantages of a program that was targeted instead on sending a human directly to Mars? To what extent is research on the International Space Station likely to help remove the hurdles to long-duration space flight?

The appropriateness of the ISS and the Moon depend on the program objectives, which should be policy decisions based partially on technical feasibility and cost. An informed and open national and international discussion is needed to support these policy decisions.

The lack of widely supported objectives for NASA has led, for example, to its budget being increasingly eroded by Congressional earmarks largely, in my opinion, because there is not a perception of NASA's intrinsic value or purpose.

I worked on a precursor to the current ISS in the early 1980's and it was clearly deliberately designed as a jobs program rather than as the most cost-effective solution to human exploration. (And realistically this will always be true of a large federally funded undertaking). Because of the use of Russian launchers to supply the Station it is not in a good orbit for staging of assets for on-orbit assembly of missions to the Moon or planets. However, the ISS could be useful for studying physiology to prepare for human missions to Mars, and it is important to keep our commitments to our international partners who have invested a large amount of resources and who are waiting to have their hardware installed on the Station.

The ISS will help human space exploration if its mission is focused on research on the impacts of living in space on the human physiology and psychology. The President's vision takes this step, however several things are needed to make this work that are not currently in the Station design, for example:

- A centrifuge to explore impacts of partial gravity on recovery from bone loss and muscle weakness. Will astronauts be able to function in the 3/8 gravity of Mars after a several month zero-g passage?

[4] Crouch, Geoffrey, "Researching the Space Tourism Market," Presented at the annual Conference of the Travel and Tourism Research Association, June 2001.

[5] AIAA–90–3785, "Site Characterization Rover Missions," D.S. Pivirotto, Sept. 25–28, 1990, Huntsville, AL.

[6] http://www.spacetoday.org/History/SpaceFactoids/SpaceFactoids3.html, "Apollo 17 astronaut Harrison Schmitt, the first geologist in space, found the most colorful stuff on the Moon—orange glass—near Shorty Crater. That suggested the possibility of ice within the Moon."

[7] "Opportunity Rover Finds Strong Evidence Meridiani Planum Was Wet," March 2, 2004 Press Release, http://marsrovers.jpl.nasa.gov/newsroom/pressreleases/20040302a.html

- Radiation research. The ISS is protected by Earth's magnetic field but the radiation environment on Mars is very severe because Mars lacks a magnetic field and a thick atmosphere.

Phase-out of the Shuttle in 2010 will make it very difficult to operate the ISS even if construction can be completed by then. Even if there is not another failure before the end of the ISS there is predicted to be a four-year gap between the end of the Shuttle and the availability of the crew exploration vehicle. Human transport can continue to rely on the reliable Russian launchers and landers. However, while European, Russian and Japanese vehicles can supply the Station, none of these is designed to bring cargo *down,* so any large science instruments must either be thrown away or not used if the Shuttle is not available. The current plan scraps alternate U.S. cargo carriers.

The Moon is a complete diversion from human missions to Mars. The suggestion that there are materials on the Moon that can be used to build systems to go to Mars is totally unfounded. The Moon has no useful resources for Mars exploration. (Water at the poles is problematic, and even if it exists is probably infeasible to "mine" in large quantities.) Everything taken to the Moon must be lifted out of the gravity well of the Earth. Even if resources did exist on the Moon, which would be useful, the mass of equipment to mine them in quantities required for a Mars mission would far exceed the benefit of launching to Mars from the lower lunar gravity.

The high cost of building a lunar infrastructure will divert resources from Mars with no added value for Mars missions because the cost of lifting equipment to Moon will far exceed the benefits.

There is little technology commonality between the Moon and Mars because of the different environments. For example, space suits designed for vacuum will not work in the Martian atmosphere. Landing systems on Mars can make use of the atmosphere unlike those for the Moon. Thermal environments between Moon and Mars are radically different. And so on.

The Moon is a scientifically interesting place in its own right but missions of exploration including the installation of large astronomical telescopes on the far side can be done robotically. Even modern science fiction does not revolve around an economically viable Moon, and previous assumptions of plentiful water on the Moon have been shown not to be true. For example, Heinlein's *The Moon is a Harsh Mistress*[8] was based on an economy, which grew grain using vast stores of underground water.

Helium 3 mined on the Moon and "burned" in a fusion reactor is often touted as a boon for energy production.[9] However, both Helium 3 mining and fusion technology are completely unproven, and a positive benefit/cost ratio has not been demonstrated. Furthermore, even if fusion and mining technologies were feasible, they will not be relevant to space exploration in any meaningful time frame.

The President's initiative also mentions Libration Points, Asteroids, etc. as destinations, but there appear to be no benefits of these objectives to Mars exploration (or to human exploration) and more justification is needed if they are selected.

Mars is probably the only human-accessible place in the Solar System for sustained human presence.

- The Opportunity rover and the Odyssey orbiter have found past and present water. Future missions will determine locations and quantity of extant water, which may be inadequate to support humans.
- The moons of the Outer planets have ample water supplies but are too distant and dangerous for humans to explore for generations.
- Modern science fiction provides reasons and scenarios for a human presence on Mars, for example:
    - — *Red Mars, Green Mars,* and *Blue Mars* (Kim Stanley Robinson)[10]
    - — *Mars* and *Return to Mars* (Ben Bova)[11]
    - — *Moving Mars* (Greg Bear)[12]
    - — *Voyage* (Stephen Baxter)[13]

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[8] Berkley Publishing, 1966

[9] http://www.space.com/scienceastronomy/helium3—000630.html, "Moon's Helium-3 Could Power Earth" By Julie Wakefield, Special to SPACE.com, 30 June 2000.

[10] Bantam Books 1993, 1994 and 1996

[11] Bantam Books 1992 and 1999

[12] Tor Science Fiction, 1994

[13] Harper Collins, 1996

Does the proposed initiative achieve the proper balance among NASA's activities? Particularly, is the balance between exploration, space science and Earth science, and between human and robotic missions appropriate?

This question is very difficult to answer because a much more detailed architecture is needed to see what balance is actually being achieved.

The cost of the program needs to be analyzed. The only mission that has been identified for sacrifice is the Hubble servicing. And in fact I believe a robotic servicing mission could be designed and implemented for the price of a single Shuttle launch. Technology to grapple with a spinning satellite has been available since the late 1980's[14] and it should be relatively simple to keep Hubble running using a robotic Orbital Maneuvering Vehicle.[15] The OMV would then be useful for on-orbit construction and servicing and is usually included in human exploration mission designs. This approach would not risk humans to service Hubble but also would probably not save any money.

History shows that the real costs of a large program cannot be reliably estimated until five to ten percent of the funds have been expended. However many, many studies of human exploration have been done over the years and if the best were "mined" at least rough estimates should be feasible now.[16,17,18,19]

What criteria should be used to determine whether robots or humans should conduct particular science and exploration missions on the Moon and Mars? What missions should only humans conduct on the Moon and Mars?

Humans *and* robots should be part of an integrated program. It is not humans *vs.* robots but how a partnership of "metal and mortal" can be most effectively used. Criteria should be extracted from program objectives (why, where, when?) which should be the subject of national and international discussions and debates. A number of studies and publications have addressed this.[20,21]

Humans will never "only" conduct missions by themselves. Robots will always be necessary as precursors, preparers and partners for humans. As mentioned earlier, robots are extensions of human perception. They currently act as scouts to determine safe and interesting places for people to operate. They will be used to prepare those places for humans by making fuel from in situ resources and building infrastructure. They will support humans by fetching and carrying, exploring beyond the reach of human habitats and transports, and carrying cargo to and from Earth.

If the costs of carrying out the President's proposal increase above what NASA currently projects them to be, would you recommend that NASA adjust the schedule for achieving specific milestones of the President's vision or use the budget authority from other NASA programs not related to the President's vision (e.g., Earth science or aeronautics research and development)?

NASA has not specifically projected the costs of the President's proposal and to some extent this is appropriate since a detailed analysis and design has not been done. However, costs can be inferred.

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[14] IAF–87–24, "NASA's Telerobotics R&D Program: Status and Future Directions," D.S. Pivirotto and G. Varsi, Brighton, United Kingdom, 10–17 October 1987.

[15] http://www.abo.fi/?mlindroo/Station/Slides/sld011.htm

[16] *NASA Leadership and America's Future in Space,* A Report to the Administrator by Dr. Sally K. Ride, August 1987.

[17] *Report of the 90–Day Study on Human Exploration of the Moon and Mars,* NASA, Washington DC, 1989.

[18] *Pioneering the Space Frontier,* the Report of the National Commission on Space, Bantam Books, 1986.

[19] *America at the Threshold: America's Space Exploration Initiative,* Report of the Synthesis Group, 1991.

[20] Pivirotto, D.S., "A Goal and Strategy for Human Exploration of the Moon and Mars," published in the *Journal of Space Policy,* 0265–9646/90/030195–14, 1990 Butterworth-Heinemann Ltd.

[21] Pivirotto, D.S., "A Goal and Strategy for Human Settlement of the Moon and Mars: Part Two," Case for Mars IV, Boulder, CO, 4–8 June 1990.

- A program cost of about $170B through 2020 can be inferred from the NASA 2005 budget projections.[22] This is less than half of the DOD budget for 2005 alone.[23]
- A lower bound estimate of about $50B for a single human Mars mission was projected by Robert Zubrin in *A Case for Mars.*[24]
- Costs of up to $450B (in 1990 dollars)[25] have been projected by NASA studies.
- Certainly the $11 or $12B called out for the Crew Exploration Vehicle will only produce a human carrier with no place to go except the ISS. There is no mention of the much larger costs of launch, on-orbit assembly, infrastructure at the Moon and/or Mars, etc.
- Robotic Mars missions are costing around $400M apiece which is the equivalent of about one STS launch.

The proposed phase-out of the STS in 2010 is extremely risky for the ISS and for exploration. Such a risk led to the dependence on the development of the Shuttle to re-boost Skylab, the first space station. When the Shuttle development did not meet the projected schedule Skylab re-entered the atmosphere and was lost. It is also not clear that any new systems will be substantially safer than an upgraded Shuttle.

The question of which missions should be sacrificed to the human exploration initiative is one of public policy. So far the budget appears to continue to support science missions, but the real costs and sacrifices have not been identified past 2005.

The schedule must reflect budget realities and the entire NASA budget would have to be greatly increased to carry out the program. Even the sacrifice of science or technology would probably not provide the resources needed with the current plan.

Observations and Recommendations:

Fundamentally the whole approach needs to be re-thought. NASA continues, as it has for its entire existence, to pursue the approach that Wernher von Braun proposed in *Collier's* Magazine in 1952—rocket launches, a space station, lunar and Mars bases.[26] This approach can be visualized by watching the movie *2001: A Space Odyssey.* But times have changed and we need to look at new approaches:

- New Ideas and Analysis Tools: Since Apollo NASA has had few new ideas about how to explore space. A recent presentation by a young NASA engineer showed exactly the same visualization and study tools[27] as my colleagues and I used in the late 1980's and was a rehash of the same concepts we were studying then.[28]
- New technologies: For example, the space elevator, the subject of Arthur C. Clarke's 1956 *Fountains of Paradise*[29] appears to be close to being enabled by structures built with carbon nanotubes and commercial ventures are being undertaken to build one. This is a system that puts a space station in a geosynchronous orbit 23,000 miles above the Earth and lowers a cable to a point on the equator. Once this (admittedly expensive) infrastructure was in place it could be used to launch payloads beyond Earth orbit. A preliminary design and cost estimates for a commercial space elevator system[30] were funded by

[22] http://www.nasa.gov/about/budget/ Administrator O'Keefe's Budget Presentation, Chart 14, 2.24.04

[23] http://www.defenselink.mil/releases/2004/nr20040123–0263.html, Defense Department Announces 2005 Budget Request, No. 046–04, January 23, 2004.

[24] Touchstone Books, 1996

[25] Costs estimated during the NASA "90 Day Study" have been widely quoted but never officially published: NASA, *Report of the 90–Day Study on Human Exploration of the Moon and Mars,* NASA, Washington, D.C., 1989.

[26] http://www.astronautix.com/lvs/vonbraun.htm, 1952 Feb. 11—*Collier's* Man Will Conquer Space Soon, *Collier's* Magazine, published papers from First Symposium on Space Flight, under the title "Man Will Conquer Space Soon." This was an important step in the popularization of the idea of manned space flight.

[27] Geffre, J., "A Summary of Recent NASA Exploration Architecture Studies," National Academies Workshop, "Stepping Stones to the Future of Space," 23 February 2004, chart 10 compare with page 45 of next reference.

[28] JPL Document, "A Robotic Exploration Program: In Response to the NASA 90–Day Study on Human Exploration of the Moon and Mars," 1 December 1989.

[29] Downloadable Edition http://www.amazon.com/exec/obidos/tg/detail/-/B000063JZ3/ref=lpr_g_4/103-0149313-3021408?v=glance&s=ebooks

[30] *The Space Elevator: A Revolutionary Earth-to-Space Transportation System,* Publisher: Bradley C. Edwards & Eric A. Westling; ISBN: 0972604502; (January 14, 2003).

the NASA Institute for Advanced Concepts which routinely provides seed funding for innovative space exploration concepts. However, none of NASA's human exploration studies are looking at anything creative like the use of a space elevator.[31] This is not to say that it is the answer, just that new approaches enabled by new technology should be considered.

- New Economics: Wealthy people are entering the game. Dennis Tito and Mark Shuttleworth are the vanguard of space tourism and many companies are vying to put people in orbit. A new bill to provide regulatory standards has just passed the House of Representatives.[32] Some examples of new launch companies, with their backers, are:[33]
  - — Scaled Composites—Paul Allen
  - — Armadillo Aerospace—John Carmack
  - — Space Exploration Technologies—Elon Musk
  - — Blue Origin—Jeff Bezos
- New ways of doing business: NASA is proposing a series of "challenge" prizes to stimulate innovative approaches to space exploration.[34] However, this is not a substitute for a well-planned program with specific, affordable goals and it still leaves NASA firmly in control. What is the process for infusing the successful approaches into the human exploration program? Or, what is the process for substituting successful approaches for the government-provided elements?
- New international players: China's *Shenzhou* program has orbited its first taikonaut. The U.S. needs either to compete or cooperate with the Chinese but the current vision is silent on this.
- New Culture: NASA has become, over the years, an entrenched bureaucracy shaped by political considerations such as keeping jobs in particular states and Congressional districts. The *Columbia* Accident Investigation Board stressed the need for culture change[35] and NASA is bringing in new personnel, mostly military,[36] to help with that situation. However, the plans for the initiative which are based on the military model (such as "spiral" and "block development" that are used successfully for aircraft production)[37] may not be applicable to the relatively small number of vehicles involved in human space exploration. NASA is attempting to revitalize its workforce[38] and improve its management practices.[39] However, the fundamental nature of the civil service-staffed centers will make it very difficult to create real change. Approaches such as converting the centers from civil services to contract organizations such as the Jet Propulsion Laboratory should be explored. Attempts to "privatize" fundamentally non-profit endeavors, such as the United Space Alliance's contract to maintain the Shuttle, are merely disguising ordinary government contracting as private enterprise.

A very recent report of a workshop of the National Academy of Science gives guidance for formulating human space exploration objectives. One point that it makes is: "Much of the success of the success of NASA's science programs was attributed to having clear long-range goals and roadmaps that are framed by scientists and periodically reassessed by the science community in the light of new knowledge and

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[31] Mankins, J.C., "Advanced Systems, Technologies, Research and Analysis to Enable Future Space Flight Capabilities and Realize the U.S. Vision for Space Exploration," presented to Stepping Stones to Space National Academies Workshop, 23 February 2004.

[32] "House Approves H.R. 3752, The Commercial Space Launch Amendments Act of 2004," http://www.spaceref.com/news/viewpr.html?pid=13774

[33] Horvath, Joan, "Blastoffs on a Budget," to appear in *Scientific American,* April 2004, Volume 290, Number 4.

[34] "NASA exploration office charts new procurement territory," March 3, 2004, http://www.govexec.com/dailyfed/0304/

[35] http://anon.nasa-global.speedera.net/anon.nasa-global/CAIB/CAIB_lowres_chapter9.pdf, Report of *Columbia* Accident Investigation Board, Volume I, Section 9.3. Long-Term: Future Directions for the U.S. in Space—"The Board Does believe that NASA and the Nation should give more attention to developing a new "concept of operations" for future activities.. . ." Page 210.

[36] http://www.spaceref.com/news/viewsr.html?pid=12052

[37] http://www.spaceref.com/news/viewsr.html?pid=12052, Briefing Charts: NASA Associate Administrator Craig Steidle, Office of Exploration Systems Chart 14.

[38] http://nasapeople.nasa.gov/hclwp/index.htm

[39] http://www.spaceref.com/news/viewpr.html?pid=13739

capability."[40] An example of this is the current Mars Exploration program which sends robotic missions every 26 months to "follow the water" to investigate whether life might have ever existed on Mars.[41] The current successful Mars rovers are a result of this approach.

Unfortunately the President's vision skips over the need for a process to provide goals for the program. Like most other human programs it merely states goals and plunges directly into an implementation strategy. This has been shown over and over to be a flawed strategy as I point out in a paper presented in 2000 at a workshop planning Human Exploration.[42] In this paper I made recommendations that I still regard as important for achieving what the President's strategy lacks:

- "Customer" Input—for example through "deliberative polling"[43] and surveys.[44] This would be from and by people outside NASA and the government, and outside the standard NASA advisors such as the National Academies, and even outside the aerospace engineering and science community. The people are paying for it, shouldn't they have a real say?
- A flexible, step-by-step approach with planning and redesign in response to things learned, either from science, engineering or economic/policy changes, in other words a "decision tree" approach with options to be exercised based on learning.[45]
- Honesty, openness, flexibility, patience and hard-nosed, non-political management.[46,47]

I recommend that the Committee urge the Administration to create a process for developing a truly fresh approach to the exploration of space. There should be a workshop or series of workshops to infuse non-NASA, non-government ideas into the selection of a vision. Then there should be a study effort over the next year or so to generate new concepts, bring in new players, fully engage the public and develop a set of goals.

The process should include, for example:

- Creative individuals, for instance Science fiction writers and movie producers
- Contestants in University robotics competitions
- Scientists and engineers
- Space Entrepreneurs
- Interested public
- Formal and informal educators
- Public Relations people
- Potential international participants.

Finally, a process should be developed for driving the human space exploration with the results of this study. This will not be an easy task, as government institutions are not accustomed to such an open process.

The Objective: Define a new vision and new architectures and approaches for human space exploration and a program to carry them out. The Science Fiction Museum and Hall of Fame would be delighted to participate in such a process.

Thank you.

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[40] Issues and Opportunities Regarding the U.S. Space Program: A Summary Report of a Workshop on National Space Policy (2004) Space Studies Board (SSB), Aeronautics and Space Engineering Board (ASEB).

[41] AIAA 96–0333, "Mars Exploration Program Strategy: 1995–2020," D.L. Shirley and D.J. McCleese, Jan 15–18, 1996, Reno, NV.

[42] Shirley, D.L., "The Myths of Mars: Why We're Not There Yet and How to Get There," Workshop on Concepts and Approaches for Mars Exploration, Lunar and Planetary Institute, Houston, TX, 18–20 July 2000.

[43] NASA Human Exploration and Development of Space Enterprise: A Concept Paper On "An Over-Arching Enabling Process for the Development of an Engagement Plan," D. Powe, L.A. Ritchie, and D.L. Jackson.

[44] http://www.planetary.org/html/society/press/survey_results.htm, 50,000 People Jam Planetary Society Website to Take Space Survey about NASA Priorities.

[45] For instance see "Pivirotto, D.S. "Assessing Risks and Mars Benefits of Lunar oration," 1991.

[46] Shirley, D.L., Written Testimony or the Root Causes of the Mars Surveyor 98 Mission Failures, 30 April 2000.

[47] ASEE 2002–406, Shirley, D.L., "Managing Creativity: A Creative Engineering Education Approach," 2002 American Society for Engineering Education Annual Conference, 2002.

[1] *Issues and Opportunities Regarding the U.S. Space Program: A Summary Report of a Workshop on National Space Policy,* NRC Space Studies Board and Aeronautics and Space Engineering Board (2004).

BIOGRAPHY FOR DONNA L. SHIRLEY

PRECIS

Donna Shirley is Director of the Science Fiction Museum and Hall of Fame in Seattle, Washington. She recently retired as Assistant Dean of Engineering and Instructor of Aerospace Mechanical Engineering at the University of Oklahoma (OU) where she led strategic planning and the development of innovative engineering education programs, and was also President of Managing Creativity, a speaking, consulting and training firm. She is a well known educator, speaker, consultant and trainer on the management of creative teams. Ms. Shirley has an MS in Aerospace Engineering and three honorary doctorates, plus over forty years experience in engineering of aerospace and civil systems, including thirty years in management. She had a 32-year career at NASA's Jet Propulsion Laboratory, culminating in the position of Manager of the Mars Exploration Program.

SUMMARY OF EMPLOYMENT HISTORY

Science Fiction Museum and Hall of Fame

- January 2003–Present: Director of a unique, interactive science fiction museum in Seattle, WA.

Managing Creativity

- 1997–Present: President of Managing Creativity. Providing speaking, consulting and training on the management of creative teams.
- 1998–2001: Co-creator and Official Spokesperson, White House Mars Millennium Project, a nationwide educational project for K–12 students.

University of Oklahoma

- September 2002–2003:Instructor of Aerospace Mechanical Engineering (AME).
- September 1999–September 2002: Assistant Dean of Engineering for Advanced Program Development. Led the creation of a strategic plan for the College of Engineering. Led the modernization of the Aerospace Engineering curriculum into an "intelligent aerospace systems" program. Acted for one year as the Interim Director of Engineering Education for the College, focussing on project-based, multidisciplinary engineering.
- 2000–2004: Served on National Research Council Task Forces on the Usefulness and Availability of NASA's Earth and Space Science Data, and the National Aerospace Initiative.
- 1998–2001: Co-creator and Official Spokesperson, White House Mars Millennium Project, a nationwide educational project for K–12 students.

Jet Propulsion Laboratory (JPL)
California Institute of Technology Pasadena, California (1966–1998)

- 1994–1998: Manager of the $150 million/year Mars Exploration Program, which included the highly successful Pathfinder and Mars Global Surveyor missions plus two additional missions to Mars every 26 months until at least 2005.
- 1992–1994: Mars Pathfinder Microrover Flight Experiment Manager. Leader of the team which developed Sojourner Truth, the $25 million Microrover landed by Mars Pathfinder on July 4, 1997.
- 1991–1992: Cassini Project Engineer. Chief Engineer of a $1.6B project to explore Saturn.
- 1989–1993: (Additional Duty) Leader of two NASA-wide, award-winning teams which developed systems engineering and project management processes for the National Aeronautics and Space Administration.
- 1990–1991: Manager of Exploration Initiative Studies.
- Various management and technical positions from 1966.

EDUCATION

- Some work in a Ph.D. Program in Human and Organizational Systems—The Fielding Institute, Santa Barbara, CA, 1997–1998.
- MS Aerospace Engineering—University of Southern California, 1968.
- BS Aerospace Mechanical Engineering—University of Oklahoma, 1965.

- BA Professional Writing—University of Oklahoma, 1963.

SELECTED CURRENT AND RECENT AWARDS, HONORS, OFFICES

- Honorary Doctorates: University of Oklahoma, Mt. St. Mary's College, Los Angeles, California, State University of New York, Rome/Utica
- Oklahoma Women's Hall of Fame
- University of Oklahoma College of Engineering Distinguished Graduate Society
- National Space Society Wernher von Braun Award
- Western Engineer's Society Washington Award for Engineering Achievement
- American Society of Mechanical Engineers, Holley Medal for Lifetime Achievement
- *Glamour* Magazine "Women Who Do and Dare" Award
- One of *MS* Magazine's "Women of the Year"
- Women in Technology International Hall of Fame
- NASA Outstanding Leadership Medal for management and systems engineering
- Society of Women Engineers Judith Resnick Award
- President of the Science Council for the NASA Institute of Advanced Concepts
- Member of the Board of Omniplex Science Museum in Oklahoma City, Oklahoma
- Member, American Society for Engineering Education
- Trustee of Scripps College for Women, Claremont, California

SELECTED RECENT PUBLICATIONS

- Striz, A. and Shirley, D., "Intelligent Aerospace Systems: An Exercise in Curriculum Development," ASEE Midwest Section Meeting, University of Missouri-Rolla, September 10–12, 2003.
- Miller, D.P., D. Hougen and D. Shirley, The Sooner Lunar Schooner: Lunar Engineering Education, *Journal of Advances in Space Research,* Vol. 31/11, pp. 2449–2454, 2003.
- Shirley, D., Baker, R., Deaton, L. and Reynolds, E., "Tinker Air Force Base Phase I Process Improvement Methodology Report," 31 May 2003.
- ASEE 2002–406, "Managing Creativity: A Creative Engineering Education Approach," D.L. Shirley, ASEE National Conference, June 2002.
- Shirley, D.L. "The Myths of Mars: Why We're Not There Yet, and How to Get There," Workshop on Concepts and Approaches for Mars Exploration, Lunar and Planetary Institute, Houston, TX, 18–20 July 2000.
- Shirley, D.L, Written Congressional testimony on "The Root Causes of the Mars Surveyor 98 Mission Failures," requested by the staff for the House Subcommittee on Science and Technology and used in hearings on 30 April 2000.
- Shirley, D.L. "Women in Engineering: Focus on Success," Bridge, National Academy of Engineering, Summer 1999.
- Shirley, Donna L., *Managing Martians,* Autobiography published by Broadway Books, with Danelle Morton, 1998, 1999.
- Shirley, Donna L., "Touching Mars," presented at the IAA Low Cost Systems Conference, Pasadena, CA, August 1998.
- Shirley, Donna L. and Matijevic, Jacob, "Mars Rovers: Past, Present and Future," Princeton University Space Studies Institute's 20th Anniversary Conference, Princeton, NJ, 10 May 1997.
- Shirley, D.L. and Haynes, N., "The Mars Exploration Program," Space Technology and Applications International Forum (STAIF–97), Albuquerque, NM, 26–30 January 1997.

SELECTED MEDIA APPEARANCES

- Recent (1996–2004) Television Appearances include: Masters of Technology Show #105, Donna Shirley SPACE TECHNOLOGY (http://www.sciam.com/mastertech/), (2002), ABC's *World News Tonight,* ABC's *Good Morning Amer-*

ica, NBC's *Today,* many CNN news programs, the Discovery Channel's *Life on Mars?,* PBS's *Jim Lehrer News Hour,* The Family Channel's *To the Moon and Mars, LA Life and Times* on KCET public television, *Charley Rose, Tom Snyder,* CSPAN, documentaries by PBS, the BBC, and Australian television, and many other television news programs.

- Numerous national and international radio appearances including local and national commercial and educational networks and PBS.
- Print and Electronic Media: Widely quoted and featured in major print media.
- Have given literally hundreds of speeches, nationally and internationally, on management of creative systems, space exploration, education, and diversity.

3911 Bagley Avenue North
Seattle, WA 98103
6 March 2004

Rep. Sherwood Boehlert
Chairman, The House Committee on Science
The Congress of the United States
Washington, D.C.

Dear Rep. Boehlert:

I am pleased to testify before the Committee on Science hearing entitled *Perspectives on the President's Vision for Space Exploration* on Wednesday, March 10, 2004, at 10:00 a.m. in room 2318 of the Rayburn House Office Building.

I certify that I have no current source of federal funding which directly supports this subject matter.

Sincerely,

Donna L. Shirley

Donna L. Shirley

Chairman BOEHLERT. Thank you very much, Dr. Shirley.

We just have five minutes, so Dr. Young, we are going to pause right now. And you know the drill. You are all veterans up here. We will do our best to get back in a timely fashion. If you would like a cup of coffee or anything or use the Chairman's lounge, you may do so. We will be back as soon as possible.

[Recess.]

Chairman BOEHLERT. Dr. Young.

STATEMENT OF DR. LAURENCE R. YOUNG, APOLLO PROGRAM PROFESSOR, MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT); FOUNDING DIRECTOR OF THE NATIONAL SPACE BIOMEDICAL RESEARCH INSTITUTE (NSBRI)

Dr. YOUNG. Mr. Chairman, thank you for the privilege of addressing you on this question. Let me say, at the outset, that I am in favor of the human exploration of Mars. I was personally aware of the risk of human space flight during my role as an alternate payload specialist on STS-58. I am now back in the equally hazardous environment of Cambridge, Massachusetts from which station I have tried to answer the questions that were addressed to me by your Committee, and I will limit myself to comments on the four questions concerning the human physiological challenges of the proposed Mars mission.

First, what are the most significant physiological challenges, and what is being done about them? They are, as you are well aware, bone loss, muscle loss, cardiovascular deconditioning, and neurovestibular, or balance organ, changes, which are all challenges. With insufficient countermeasures, the long duration mission to Mars will be very deleterious. Bone loss and the related risk of fracture remains the most serious unsolved threat. Progress in treating demineralization is being made with the use of drugs. Cardiovascular deconditioning, with the associated post-flight orthostatic hypotension, which just means fainting when you stand up, may also be combated with drugs, as well as fluid loading and aerobic exercises. The neurovestibular problems can affect balance and locomotion for a considerable time after return to Earth or going to work on the surface of another planet. The overall issue, at the current time, is that the current suite of exercise countermeasures, relying primarily on treadmills, resistance devices, is unreliable, time consuming, and inadequate by itself to assure the sufficient physical conditioning of astronauts going to Mars.

Radiation, however, remains the most vexing and difficult issue. Both increases in the likelihood of cancer and possible acute radiation sickness are major concerns for any extended flights, particularly outside the Earth's magnetic field. During solar flare periods, astronauts could retreat to a small shelter to avoid the potentially high proton storms. The high-energy charged particles in the constant cosmic radiation, however, are considerably more difficult to protect against. Conventional shielding against them only makes matters worse by secondary emission of further damaging radiation. Both the flux of these particles and their impact on organs are being measured by a variety of dosimeters aboard the Space Station. The relative biological effectiveness of these heavy charged particles is also under investigation, making use of a new NASA Space Radiation Facility at the Brookhaven National Laboratory.

Some progress in drug protection against radiation threats is currently being made, but more effort is required. Magnetic shielding, long considered desirable, may also be inching toward a practical implementation using superconducting magnet technology. Much of this bioastronautic research has been conducted under the leadership and sponsorship of the National Space Biomedical Research Institute and the Johnson Space Center. They had a critical road—a "Critical Path Roadmap" developed to guide the selection

of peer-reviewed research proposals. This roadmap, incidentally, is about to be reviewed by a panel led by the Institute of Medicine.

Both the microgravity and the radiation threats, of course, are reduced by shortening the transit time to several months and using the local soil for adding shielding to the surface of—on the surface of the Moon or Mars. Advanced technology propulsion could shorten the voyage and mitigate the threats as well as ease the serious psychosocial challenge of the small groups working and living in isolation.

The second question was the need for the Station to continue research to solve these problems. The Station, although potentially the ideal laboratory for research into all of microgravity science, has not yet been used effectively for several reasons. It is still under construction and has a limited crew. There is not enough time available for human research, but we can make sufficient progress to take advantage of its presence in the future. The keys to fulfilling the potential of the Station are peer-reviewed, mission-directed science, an expanded crew, installation of the key biomedical equipment on-board, timelier accelerated use—launching of the Centrifuge Accommodation Mission, and utilization of the Station as a testbed for technology for development of advanced life support systems.

Finally, the most important piece of additional equipment to meet the research goals is a short radius human centrifuge for the study of intermittent artificial gravity inside the Station, possibly the "universal antidote" we have been shooting for.

In closing, Mr. Chairman, I would like to say something about a question that was not posed to me, and that is the importance of the Mars mission, as well as the Station, for education and outreach. It has often been claimed that human space exploration serves to motivate students and teachers to emphasize science and mathematics in the educational process. I can state from personal experience, with some of the country's best young, minds that this is certainly true. The excitement of human space flight and the recognition of the daunting nature of some of the tasks invigorate the very students we most need to continue to drive the science and technology engine of our society. The National Space Grant Program, for example, regularly contributes to the education of many thousands of youngsters who have seen the stars and remain committed to the space program. The proposed Moon/Mars mission will only expand this level of interest in my opinion.

Thank you.

[The prepared statement of Dr. Young follows:]

PREPARED STATEMENT OF LAURENCE R. YOUNG

Outline of responses to key questions posed by the Committee:.

Q1. What are the most significant human physiology challenges? How daunting? When will they be resolved? How much research has been done and where was it conducted?

Bone loss, muscle loss, cardiovascular deconditioning and neurovestibular alterations are all known challenges. The longer the space flight the more serious the after-effects of weightlessness. With insufficient countermeasures the long duration flight using conventional propulsion (nine months to Mars, month to a year on the surface at 3/8 g, and 6–9 months back to Earth), the microgravity effects will be very deleterious. Current countermeasures (aerobic and resistive exercise as in ISS),

although inefficient and onerous for some astronauts, are reasonably effective against some of the muscle and cardiovascular losses—but have only limited effectiveness in countering the full range of dangerous bone weakening. Bone loss and the related risk of fracture remains the most serious unsolved threat. Progress in treating demineralization is being made with use of drugs (bis-phosphonates). Cardiovascular deconditioning and the associated post-flight orthostatic hypotension may also be combated with drugs (mydodrine) as well as fluid loading and aerobic exercise. The effectiveness of these drugs for use in space and following return is only now being determined. A protective suit can also mitigate the problem of orthostatic hypotension to some extent. It remains to be determined if some such suit will be needed or provided for landing on the Moon or Mars. Neurovestibular problems can affect balance and locomotion for a considerable time after return to Earth. This too, along with motion sickness, can threaten astronaut safety and comfort on arrival at Mars unless effective countermeasures are employed. Overall, the current suite of exercise countermeasures, relying primarily on treadmill, resistance devices, is unreliable, time consuming, and inadequate by itself to assure the sufficient physical conditioning of astronauts going to Mars.

Radiation remains the most vexing and difficult issue. Both increases in the likelihood of cancer and possible acute radiation sickness are major concerns for any extended flights outside the protection of Earth's magnetic field. During solar flare periods astronauts could retreat to a small shelter to avoid the potentially high level proton storms Galactic cosmic radiation, consists of omnidirectional fluxes of particles covering a wide range of energies. High energy charged particles in the constant cosmic radiation are considerably more difficult to protect against. Conventional shielding against them only makes matter worse by the secondary emission of further damaging radiation. Both the flux of these particles and their impact on organs are being measured by a variety of dosimeters currently aboard ISS. The very important issue of the relative biological effectiveness of these heavy charged particles is also under investigation, making use of the new NASA Space Radiation Facility at the Brookhaven National Laboratory. The Alpha Magnetic Spectrometer aboard ISS should add highly accurate determination of the flux of galactic radiation, by extrapolation from its measurements made on the Space Station. Some progress in drug protection against the radiation threat is currently being made but more effort in that direction is required. Magnetic shielding, long considered desirable, may also be moving toward a practical implementation using superconducting magnet technology .

One promising approach to the weightlessness issue is the well known but never implemented artificial gravity approach, to be discussed later. Both the microgravity and radiation threats, of course, are reduced by shortening the transit time to several months and using the local soil for added shielding on the surface of the Moon or Mars. The transit time for propulsion using conventional bi-propellant rockets is essentially determined by orbital mechanics as one coasts towards Mars. Advanced technology propulsion could shorten the voyage and mitigate the threats, as well as ease the serious psycho-social challenge of small groups working and living in isolation for long periods.

Much of the recent bioastronautics research has been conducted at universities by countermeasure development teams of university and government laboratories under the leadership and sponsorship of the National Space Biomedical Research Institute and at JSC. A "Critical Path Roadmap" and associated high priority research questions has been developed and maintained by JSC and NSBRI—and should guide the selection of peer reviewed research proposals. This Roadmap is about to be reviewed by a panel under the direction of the three Academies: NAS, NAE and IOM.

Q2. How can research aboard ISS contribute to solving these problems? What kinds of experiments and additional equipment are needed? How long will it take?

The ISS is potentially the ideal laboratory for research into all of the microgravity related issues challenging long duration exploration. It has not yet been used effectively however, for several reasons. While under construction, and with a limited crew of three (now two), no time is available for intense human research. Only one of the two Human Research Facility racks is on-board, and sample return is currently nearly non-existent. The limited results to date should not be taken as predictive of the potential benefits of the fully equipped and staffed ISS, any more than the initial flawed HST could have been used to predict its current string of successes.

The keys to fulfilling the potential of ISS in the bioastronautics areas are:

1. Support of peer reviewed, mission oriented flight experiments directed at solution of the key bioastronautcs challenges.
2. Provision of a full resident crew of six or seven, including astronauts trained and capable of doing biomedical studies and serving as test subjects.
3. Installation and resupply of the key biomedical equipment, beginning with the Human Research Facility Rack 2, and enabling the important additions in the JEM and Columbus to be added to the ISS.
4. Timely, or even accelerated, launching of the Centrifuge Accommodation Module (CAM) and performance of key experiments on animals at various g-levels. (The scientifically important research into the influence of partial gravity on animals and cells is also fundamental to understanding the problem of human deconditioning and survival in 0-g, on the Moon or on Mars.) The utilization of the CAM will, of course, require the regular upload and download of research specimens—even after discontinuation of Shuttle flights.
5. Utilization of the ISS as a testbed for technology development for advanced life support systems. Testing and evaluation of full or partially closed life support systems, essential to any long duration mission to the Moon or Mars, will be best accomplished on the ISS. If successful these advanced life support systems could then be incorporated into the infrastructure of the ISS itself, reducing operational costs and permitting larger and longer crew presence.

Finally, the most important piece of additional equipment to meet the research goals is a short radius human centrifuge for the study of intermittent artificial gravity inside the ISS. Ground studies already underway will determine the potential of artificial gravity for preventing all of the microgravity related deconditioning issues. Although early positive results will guide missions planners regarding artificial gravity, only flight tests with numerous (tens) of astronauts for extended periods (several months) will allow this "universal antidote" to be proven and applied to a Mars mission in conjunction with other countermeasures. Design studies of a moderate radius (56m) spacecraft structure, rotating at 4 rpm to provide 1-g of artificial gravity, are encouraging and the concept appears practical.

Q3. How would the research budget and number of astronauts aboard station have to be changed to accomplish the research agenda?

The proposed research budget for Biological/Physical Sciences Research ($492 Million for FY 2005) represents a substantial increase. However, to go along with an increase to six or seven crew members, the capability of conducting many more in-flight experiments, and the need for a human centrifuge on the ISS, this budget will need to increased even further. I am not prepared to speculate on the desirable level. Among the substantial number of ground research studies submitted to NSBRI and to NASA are numbers of potentially valuable and relevant flight experiments, each of which is costly. Since there have been very few flight biomedical experiments since Neurolab and STS–95, a substantial queue of accepted peer reviewed investigations already exists. Some worthwhile studies have already been "deselected" for lack of flight opportunities or relevance.

Q4. How long will the ISS have to remain in operation to produce meaningful flight information?

Because most of the human physiology experiments require long duration exposure to weightlessness and evaluation of potential countermeasures, the process of accumulating sufficient data and exploring the relevant variables is very time consuming. Initial results for countermeasure evaluation, for example, might only begin to be accumulated after four sessions of 4–6 months each. Early positive results would obviously influence both Mars mission designs and even continuing ISS crew health protection. To reach a valid scientific conclusion about particular protocols however, fuller exploration might take 8–10 test missions, or up to five years to finish. Finally, it seems prudent to complete a full-length on-orbit simulation of at least the mission to Mars, if not the entire round trip, before embarking on that voyage of exploration. Obviously a lunar base could form a key portion of this simulation, along with the ISS.

Beyond the immediate use of the ISS to answer some of the more pressing issues in human physiology associated with the Vision for Space Exploration, is the larger question of the continued need for a microgravity laboratory for science and technology. The proposal to limit ISS research to the impact of space on human health and to end support for other important microgravity science and space technology

seems short sighted. There will remain numerous important questions, in fundamental biology and physics, in the behavior of fluids and combustion, in materials and crystal growth that can only be answered in orbit. If the ISS were allowed to end its useful life prematurely we would only hear a strong cry for its replacement. I strongly believe in the scientific and technical value of a "permanent presence in space."

Additional Comments:

Education and Outreach:

It has often been claimed that the human space serves to motivate students and teachers to emphasize science and mathematics in the educational process. I can state from personal experience with some of the country's best young minds that this is certainly true. The excitement of human space flight and the recognition of the daunting nature of some of the tasks invigorate the very students we most need to continue to drive the science and technology engine of our society. The national Space Grant program, for example, regularly contributes to the education of thousands of youngsters who have "seem the stars" and remain committed to the space program. The proposed Moon/Mars mission will only expand this level of interest.

Human Exploration Of Space:

THE NEXT STEPS

By Larry Young

Exercise on the treadmill has been a part of the crew health regime from the early days of the shuttle program. Here, Rick Hauck is photographed exercising on the treadmill on the Challenger's mid-deck during STS-7.

Introduction

Exploration is not only about developing an understanding of the nature of distant objects in the solar system; it is also about developing a deeper knowledge of ourselves. Recall how the first voyages into low Earth orbit, more than thirty years ago, allowed us to view the Earth as never before—the wonderful pictures and the first-hand reports of the early astronauts did much to spur the ecological movement.

But there was a second, equally exciting exploration involved in these voyages as we explored the reactions of humans to the space environment. Protecting our astronauts against the hitherto *unexplored* region below one-g was a new challenge, and in their own way the results were as spectacular as the views of Earth. Space is a fundamental tool for understanding the effect of gravity on living things.

What is the next step for humans in space? Dan Goldin, the NASA Administrator, said last year, "Our goal should be a sustained presence on Mars and in the solar system and not a one-shot, feel-good, spectacular mission." The challenge of Mars is fascinating, whether or not the Mars meteorites contain fossils.

There are criticisms, in both the U.S. and abroad, of large programs geared to the human exploration of space. There is no doubt that certain scientific goals are carried out better and cheaper away from the constraints of a crewed platform. The planetary community itself is divided about human Mars exploration—with many feeling that the risk and expense are not worth the expected scientific return. Without reviewing the benefits of a human mission to Mars as a national goal, however, let us assess where we stand in terms of our knowledge of how humans would tolerate a voyage of this type, and what the missions aboard the International Space Station will teach us to help us attain such a lofty goal.

Photo: NASA and RSA

A great deal of information on human health on long-duration spaceflights is being derived from Shannon Lucid's record-breaking 188-day stay aboard the Mir space station.

The Gravity Factor

Gravity is perhaps the most important environmental factor affecting the development of life on Earth—yet it has been difficult to study its effects because it can't easily be "turned off." Ralph Pelligra put it nicely: "We are the children of gravity. We can't touch it or see it. But it has guided the evolutionary destiny of every plant and animal species and has dictated the size and shape of our organs and limbs."

The human organism is well adapted to its natural environment of 1-g, in which it has evolved and developed. Consider a few of the obvious influences of gravity on our body. Our cardiovascular system adjusts peripheral resistance and heart rate to maintain pressure and flow as we go from supine to erect. Check valves in our veins and the surrounding muscle prevent blood from pooling in our legs under the gravitational load. Our skeletal system is engineered to withstand the static and dynamic loads of body weight. Our nervous system uses information about the vertical to keep us from falling even in unusual activities. However, these systems are not designed for operation in other than momentary periods of free-fall.

Shortly after Sputnik's launch, the National Research Council's Committee on Bioastronautics warned that human spaceflight was problematic and might entail such symptoms as anorexia, nausea, sleeplessness, hypertension, and tachycardia. Fortunately, if these symptoms did occur during the Mercury and Gemini missions, they were limited to the ground controllers! By the time of the Apollo mission series, with its larger vehicles that permitted more crew activity, the U.S. had recognized—as the Russians had done earlier—that space adaptation syndrome was a problem.

Human Adaptation to Space

Let me briefly take you through a typical, if somewhat simplified, space flight and its physiological consequences. When people go into space, a well-established pattern of adaptation takes place, more or less as follows. The most obvious first reaction is space motion sickness, a malady like sea sickness that strikes about two-thirds of all astronauts and lasts from one to three days. It is quite debilitating, but can usually be controlled by an intramuscular injection. Fluid begins to shift from the legs to the chest and head even before launch (as the astronauts lie on the pad with

legs elevated) and continues to shift in weightlessness—producing the puffy faces and spindly legs so commonly seen in crew pictures. The body reacts to this shift by dumping the excess fluid (including blood plasma and interstitial fluid) by altering the kidney response, and by reducing thirst and water intake. The human body loses from a half to one liter of fluid in the first day.

This leaves a relative excess of red blood cells—more than are needed to do the job of oxygen transport in the easy environment of weightlessness—so that too is regulated. Even though iron is taken up by the bone marrow, red blood cell production is cut off, and the normal death of the cells produces a gradual decline in red blood cell count of about one percent per day for short missions. Meanwhile, the circulation has an easy time of it—since it no longer has to push blood uphill to the brain some of the pressure-regulating reflexes fall into disuse. Although the amount of blood ejected from the heart on each stroke is increased (and heart rate remains unchanged in space), blood pressure doesn't go up—so obviously the resistance against the fluid flow is decreased. The venous system becomes more compliant, too, as it no longer has to use muscle tone to return blood uphill to the heart.

The large muscle groups that support our weight—in the legs, back, and neck—begin to deteriorate with no job to do, just as they would if they were in a cast. Similarly, our bones, which are normally continuously rebuilt, appear not to absorb calcium from the blood to form new bone, and gradually but steadily lose mass and strength. The stress response of both launch and re-entry causes an increase in the breakdown of protein in the body. Even the immune system isn't immune to the effects of microgravity—and exposure to weightlessness interferes with the effectiveness of lymphocytes in fighting infection.

Although these changes are expected in microgravity, they present some serious danger for the return, especially if the astronauts are physically stressed. They may experience "Earth sickness" and become disoriented with every head movement. Posture and walking are disturbed. Their cardiovascular system will generally not support the unaccustomed hydrostatic load associated with standing quietly, and orthostatic hypotension with a tendency to faint usually ensues. The muscles are in danger of tearing under sudden loads, and the bones may be so weak as to fracture easily.

Long-Duration Spaceflight Considerations

In the absence of advanced boosters or extensive orbital ferries, a Mars mission entails a trip of two to three years. Once on the Martian surface, with its 3/8 Earth gravity, and suited for protection in its inhospitable atmosphere, astronauts must be fit for work. For a human Mars mission, mere survival in weightlessness is not sufficient. The astronauts on the foreign planet must be ready to function effectively as geologists, geographers, biologists, chemists, and engineers. We cannot afford to have astronauts in a weak physical condition on any part of the mission. A weak and faint, rubber-legged astronaut, suffering from disorientation and neurotic from the isolation, will hardly be able to maximize the scientific return or bring credit to the people who sent him or her. The viability of a human mission to Mars without substantial further information concerning human tolerance and countermeasures to deconditioning is questionable.

Human Physiology Studies

NASA has placed a strong emphasis on the study of human physiology in space from the outset. Knowledge in this area has expanded steadily from the early Mercury, Gemini, and Apollo flights. It took a large step forward with the flight of Skylabs 2, 3, and 4; and a great deal of new information has come from the use of Spacelab in the shuttle and the recent shuttle-Mir missions.

Skylab provided the first opportunity for scientists to study habitability and physiologic adaptation in space over periods up to nearly three months. Those missions revealed many adaptation phenomena and readaptation difficulties.

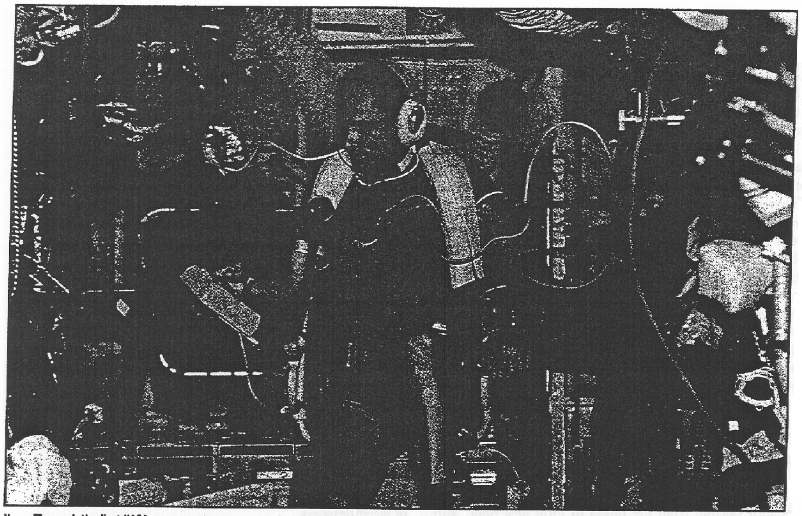
The Spacelab research facility, in which we have done most of our flight experiments, provides a shirt-sleeve atmosphere for conducting laboratory experiments in microgravity. Although Spacelab offers greater resources than Skylab, research conditions are still not ideal. Spacelab is well equipped for biomedical measurements, but flights are limited to about two weeks, which does not permit study of longer-term adaptation or study of the effectiveness of various "countermeasures" to combat the deleterious effects of weightlessness.

The Russian program, with its long history of flights lasting more than a year, revealed a number of post-flight health problems, especially in the first few days after return, but gave us little in the way of in-flight scientific measurements. The combination of some powerful monitoring techniques and long-duration flights in the current shuttle-Mir program allows us to begin assessing the manner in which exercise can help some astronauts to keep from deteriorating during months in space. However, with results compiled for only three subjects thus far, our information is too limited to allow us to generalize.

In addition to the space experiments, a great deal of the work is done using two categories of ground-based research: supporting studies that aid in the development and validation of the experiment protocol, and pre- and post-flight data collection on astronauts. The purpose of pre-flight data collection is to establish a baseline for comparison to in-flight and post-flight data. The purpose of post-flight data collection is to measure the immediate response to return to 1-g and the longer-term readaptation to 1-g.

The current status of countermeasures is in flux. Using methods that simply treat the symptoms of physiologic deconditioning is an approach that superficially is attractive, but, because the gravitation effect is ignored, is unlikely to be entirely successful.

Recent reviews of the effectiveness of extended exercise as a countermeasure on long-duration flights, including the recently completed six-month flight of American astronaut Shannon Lucid, are encouraging but not entirely conclusive. Even if they are effective, they exact an



Norm Thagard, the first NASA cosmonaut guest researcher aboard Mir exercises on the ergometer in the Mir's Base Block Module.

enormous toll in time away from productive work and in crew effort. Yet the options available to deal with long-duration weightlessness are limited.

Artificial Gravity Spaceships

One could assume that artificial gravity will be required and begin to define the parameters of radius, angular velocity, g-level, and duration. However, the conservative design, with one kilometer radius and one revolution per minute (rpm) is impractically large. An imaginative way to counter the effects of weightlessness is to spin the astronauts in a giant centrifuge, thereby creating "artificial gravity" by centrifugal force. This concept, advanced by futurists and science fiction novelists, including Willy Ley, Wernher von Braun, and Arthur Clarke, generally assumed a very large, slowly spinning torus (donut), like the one in the movie *2001—A Space Odyssey*.

The cost of such a solution is very high, both for the launch and assembly of a structure that might approach a kilometer in radius, and for the enormous amount of fuel required to spin it up to a speed of one revolution per minute (rpm), and then slow it down again when preparing for a landing or orbital rendezvous. The radius and rotation rate are based on the g-level required, but this probably needn't be the Earth's gravity. Half of 1-g or less would probably be enough to keep people fit although the rotation itself can make people motion sick while making head movements. Although one rpm is surely slow enough, people would need to slowly adapt to rates of 4-6 rpm. If astronauts could learn to move comfortably in all directions while spinning at 10 rpm, the radius of the rotating spacecraft could be brought down to four meters, while maintaining an acceleration level at the rim of 0.5 g. However, such a compact and attractive design, while easy to build and spin, would entail a rim speed of only about four meters/second, so that an astronaut running opposite to the rotation would lose contact with the floor. Furthermore, a two-meter-tall astronaut standing up in this device would find that his or her head would be at only half the artificial gravity level as his or her feet—a decidedly bizarre physiological condition!

Conclusion

Much remains to be learned about artificial gravity before it can be presented as the ultimate countermeasure for long-duration flight. However, a program involving rotating rooms and centrifuges on Earth, together with a series of animal and human space experiments, can bring us the answers we seek. Only by an orderly, long-term study on the International Space Station, along with an artificial gravity research facility, will we be able to answer the question—"Are we ready to send humans to Mars?"

Dr. Larry Young, Apollo Program Professor of Astronautics at the Massachusetts Institute of Technology, was the alternate Payload Specialist on the second Space Life Sciences shuttle mission. He directs the Massachusetts Space Grant Consortium.

BIOGRAPHICAL SKETCH

Provide the following information for the key personnel.
Photocopy this page or follow this format for each person.

NAME	POSITION TITLE
Laurence R. Young	Apollo Program Professor of Astronautics and Health Sciences and Technology, MIT

EDUCATION/TRAINING (Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training).

INSTITUTION(S) AND LOCATION	DEGREE(S) (if applicable)	YEAR(S)	FIELD(S) OF STUDY
Amherst College, Amherst, MA	A.B.	1957	Physics
Massachusetts Institute of Technology, Cambridge, MA	B.S., SM	1957/59	Elec. Engineering
Faculte de Sciences - University of Paris(Sorbonne)	Certif de License	1958	Mathematics
Massachusetts Institute of Technology, Cambridge, MA	Sc.D.	1962	Instrumentation

RESEARCH AND PROFESSIONAL EXPERIENCE: Concluding with present position, list, in chronological order, previous employment, experience, and honors. Include present membership on any Federal Government public advisory committee. List, in chronological order, the titles, all authors, and complete references to all publications during the past three years and to representative earlier publications pertinent to this application. If the list of publications in the last three years exceeds two pages, select the most pertinent publications. **DO NOT EXCEED TWO PAGES.**

Professional Experience:

1961 University of Puerto Rico, Medical School: Research on Neurophysiology
1962-67 Assistant Professor, Aeronautics and Astronautics, MIT, Cambridge, MA
1967-70 Associate Professor, Aeronautics and Astronautics, MIT, Cambridge, MA
1969-78 Harvard Medical School: Lecturer in Engineering
1970-95 Professor, Aeronautics and Astronautics, MIT, Cambridge, MA
1970-92 Director, Man-Vehicle Laboratory
1970- Professor in the Harvard-MIT Program in Health Sciences and Technology, Member of HST Joint Faculty Committee, In charge of Interdepartmental Ph.D. Program in Biomedical Engineering, Cambridge, MA
1972-73 Visiting Professor, Swiss Federal Institute of Technology (ETH)
1972-73 Visiting Professor, Conservatoire National des Arts et Metiers, Paris, France
1972-73 Visiting Scientist, Kantonsspital Zurich, Neurology Department
1987-88 Visiting Scientist, NASA Ames Research Center
1987-88 Visiting Professor, Stanford University, Electrical Engineering Department
1992-93 Alternate Payload Specialist (Astronaut), NASA, SLS-2
1995- Apollo Program Professor of Astronautics, MIT, Cambridge, MA
1996-02 Professor, Baylor College of Medicine
1997-01 Director, National Space Biomedical Research Institute, Sr. Advisor, 2002-
2002- Adjunct Professor, Mt. Sinai School of Medicine, New York
2002 Visiting Professor, College de France,Paris

Honors and Awards:

Institute of Medicine, Member, 1993; National Academy of Engineering, Member, 1980,
International Academy of Astronautics:Corr Member 1996 Full, 2001;IEEE Fellow, 1979
American Men and Women of Science, 2002, Who's Who in America 1985
Festschrift Honree; 6th Vestibular-Space Symposium, 2002;
Biomedical Engineering Society: President, Alza Lecturer, 1984
Principal Investigator, Vestibular Experiments in Spacelab-1, D-1, and SLS-1/2, Co-I IML-2, Neurolab,STS-95
Space Act Award, NASA Ames Commercial Technology Award, 1995; NASA Public Service Group Achievement,
1984 Koetser Foundation Prize (Brain Research), Zurich, 1998
AIAA Dryden Lectureship in Research, 1981; NATO Visiting Lecturer, 1975, 1987, 1997
Keynote Lecturer: American Society of Biomechanics, 2000
Research Day, Univ. of Houston, 2000; American Astronautical Society, 1990
K. D. Wood Colloquium Lecturer, Univ. of Colorado, 1999
Paul E. Hemke Lecturer in Aerospace Engineering, RPI, 1993
First Annual Space Life Sciences Lecturer, American Physiological Society, 1990, Phillip Bard Lecturer
Johns Hopkins School of Medicine, 1991
University of Toronto, First Lewellyn-Thomas Lecturer in Biomedical Engineering, 1985

US Air Force, Science Advisory Board 1979-85, Decoration for Exceptional Civilian Service, 1985
Explorers' Club, Fellow, 1980
IEEE Franklin V. Taylor Award (Human Factors), 1963
French Government and Fulbright Travel Fellow, 1957-1958

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Chairman BOEHLERT. Thank you very much, Dr. Young.
Dr. Fisk.

STATEMENT OF DR. LENNARD A. FISK, CHAIR, SPACE STUDIES BOARD (SSB), NATIONAL ACADEMY OF SCIENCES; CHAIR, DEPARTMENT OF ATMOSPHERIC, OCEANIC, AND SPACE SCIENCES, UNIVERSITY OF MICHIGAN; FORMER ASSOCIATE ADMINISTRATOR, SPACE SCIENCE AND APPLICATION, NASA

Dr. FISK. Mr. Chairman, Ranking Member Gordon, and Members of the Committee, I am pleased to have this opportunity to testify before you. As you noted, I have provided some written comments. These are based on the reports and studies, the many reports and studies of the National Research Council Space Studies Board of which I am the Chair.

I would also like to refer you, in particular, to a workshop that we held last November on the Nation's space—what the Nation's space policy should be. And I believe a summary of that workshop has been provided to you.

You asked a number of important questions, and in the time allotted to me for my remarks, let me just comment on a few of them. You asked the question whether the President's initiative is needed and justified. The answer, in my judgment, is an unqualified yes. As was noted earlier on the panel, the human space flight program of NASA has lacked direction now for decades, and it needs a clear, definitive goal, and the obvious goal is to explore. Exploration is the acquisition of new knowledge: knowledge of space as a place for human activity, knowledge of our solar system, the universe beyond, and perhaps exploration as a basic human desire innate in our genetic code. And the human space flight program can be a contributor to the modern realization of that basic trait.

You asked if NASA was properly conducting this exploration initiative. On this point, I am very encouraged. Since it appears that it is being conducted as a true exploration initiative, not a human or a robotic program, but rather one in which humans and robots each play their essential and appropriate roles. Indeed, I think one of the appealing things to me is there is an opportunity here to diminish what has been a long-standing dichotomy between space science and human space flight. An exploration program properly conducted in which humans and robots each play their appropriate roles should result in synergy between robotic science and human space flight.

It also appears to be recognized that this is a long-term endeavor. Indeed, one could argue the limited budgets that are being provided for it demand a long-term endeavor. This long-term endeavor will, as a result, need to be accomplished through a series of incremental steps. But there is a positive feature to those incremental steps as well in that it should sustain public and political support for the decades to come. Robotic missions to the Moon and Mars, laying the foundation for human exploration, a regular series of test flights of launch capabilities, the use of the Space Station to qualify humans for space, all of these things should create the appearance and the reality of progress and sustain interest and support.

You asked about the balance between other NASA activities, and on this point, there are some major concerns, particularly with the President's fiscal year 2005 budget for NASA, which begins the exploration initiative, because it has unfortunately resulted in some collateral damage for certain of NASA's science disciplines. Space science has basically been divided up into those which are considered to be essential for exploration and those which are not, and the latter has suffered some serious reductions, particularly in the out-years. I question the wisdom of this demarcation. It is important to note that this is not, in any way, a rejection of the exploration initiative, it is rather simply a lament that certain disciplines have been left out. The Sun-Earth Connections program of NASA has a goal to understand the Sun and its influence on the space environment of the solar system, and yet it has seen some serious cuts in the programs on which it depends. If we are going to, in fact, consider sending humans forth into space, it is inconceivable to me that we would not try and develop the ability to understand and predict the space environment through which we will fly. That would be like embarking on an ocean voyage of exploration without an adequate marine weather forecast.

And similarly, the exploration—definition of exploration in the President's initiative seems a bit narrow to me: the planets are in, the sun is not. The Origins of the Universe Program, which looks for life elsewhere, is in but the Structure and Evolution of the Universe Program is out. And it is as if we have divided exploration up by wavelength where we say infrared and visible light astronomy, which can reveal habitable sites, is in, but x-ray and gamma ray astronomy, which looks at the more violent parts of the universe, is out, and this does not make sense to me. And then, of course, there is Earth science, which has been badly cut.

This is a special issue. NASA has a responsibility, under the Space Act and its amendments, to use its capabilities to understand our home planet and predict its future. There is a difference, I think between priorities and responsibilities. We have the priority now to explore, but we still have the responsibility to deliver to the policy makers, and the public, a sufficient understanding of how we can be good stewards of our planetary home.

Throughout the history of NASA, the various science disciplines have each been recognized for their fundamental importance to explore, to understand, and to utilize space and have been supported equally. The proposed exploration initiative has resulted in a fundamental departure from that balanced approach.

Thank you for your attention.

[The prepared statement of Dr. Fisk follows:]

PREPARED STATEMENT OF LENNARD A. FISK

The President's Vision for Space Exploration: Perspectives from a Recent NRC Workshop on National Space Policy

Introduction

Chairman Boehlert, Ranking Member Gordon, and Members of the Committee, thank you for inviting me to testify today. My name is Lennard Fisk. I am the Thomas M. Donahue Collegiate Professor of Space Science at the University of Michigan, and I appear before you today in my capacity as the Chair of the National

Research Council's Space Studies Board. In discussing the President's vision for space exploration this morning I will be telling you about a workshop that the National Research Council held last November under the sponsorship of the Space Studies Board and the Aeronautics and Space Engineering Board. The purpose of the workshop was to discuss the question: What should be the principal purposes, goals, and priorities of the U.S. civil space program? As I will tell you, there are many ideas from that workshop that are well embodied in the President's vision for space exploration. There are also some views on implementation, which you may wish to consider. There are, however, some notable differences from what participants at our workshop thought was an appropriate approach that I would like to call to your attention.

I have brought with me and would submit for the record a list of the workshop participants and a copy of the report,[1] titled *Issues and Opportunities Regarding the U.S. Space Program: A Summary Report of a Workshop on National Space Policy,* which summarizes our discussions. As you can see from the list, the participants represented a broad range of experiences in the space program, having participated in leadership positions in NASA, industry, and the military, as well as the science community. The discussions were informed and lively, and what impressed me most was the extent to which people agreed on the key issues.

Is the President's Vision Needed?

The participants in the NRC workshop stated several times over the course of the meeting that NASA needed a clear vision, direction, and goal for the human space flight program. Furthermore, these participants were inclined to agree that such a goal should be the human exploration of the solar system beyond low-Earth orbit. They viewed exploration as the acquisition of new knowledge: knowledge of space as a place for human activity, knowledge of our solar system, and knowledge of the universe beyond our solar system. They also saw exploration as a basic human desire, innate in our genetic code, and noted that human space flight can be the modern realization of that basic trait.

Is NASA Approaching the Vision Correctly?

The important question, of course, is how does the Nation proceed in order to achieve a space exploration goal? How do we ensure success? Our workshop recognized that exploration of our solar system is a long-term endeavor, which needs to be accomplished with a series of incremental steps. In this sense, the human exploration efforts can learn from the successes of NASA's science programs. Workshop participants observed that certain key factors have contributed to the success of the science program: there are clear goals in the science program established by the science community's interest in pursuing the most challenging scientific questions; there is strategic planning; and there has been a steady sequence of accomplishments. The science program is executed via a series of individual steps that can accumulate success, from which progress can be measured and momentum sustained.

So what are these steps for human exploration? Our workshop participants envisioned a number of key efforts—the development of building block technology, the dedication of ISS research to solving questions posed by long-term space flight, eventual phasing out of the Space Shuttle, and the use of robotic precursor missions to both the Moon and Mars. These steps also are part of NASA's new roadmap for space exploration.

In 1997 the Space Studies Board published a report which I think offers several complementary ideas for a roadmap for space exploration. Titled *The Human Exploration of Space,* the report reviews three important areas of consideration that the Board felt were necessary to address at the initial stages of a program in human exploration.[2] First is the enabling science for human exploration. This defines the conditions necessary to maintain the health and safety of astronauts and to ensure their optimal performance. Research areas that are enabling science can be classified according to their degree of urgency. Critical research issues, or "showstoppers," are those for which inadequate scientific data lead to unacceptably high risks to any program of extended space exploration. The second area of consideration is the science that is enabled by a human exploration program, specifically human missions to the Moon and Mars. The third area of consideration is one of management and organization—what should be the relationship between the scientific community

[1] *Issues and Opportunities Regarding the U.S. Space Program: A Summary Report of a Workshop on National Space Policy,* NRC Space Studies Board and Aeronautics and Space Engineering Board (2004).

[2] *The Human Exploration of Space,* NRC Space Studies Board, 1997.

and NASA, between scientists and engineers within NASA, as a program of human exploration moves forward?

The 1997 SSB report identifies the following as those showstopper, critical research issues: the long- and short-term effects of ionizing radiation on human tissue; the radiation environment inside proposed space vehicles; the benefits and costs of different radiation shielding techniques; the detrimental effects of reduced gravity and transitions in gravitational forces on all of the body's systems and on bones, muscles, and mineral metabolism; and the psychological effects of long-duration confinement in microgravity with no escape possible. These and several other issues related to the human biological response to space exploration are detailed and prioritized in two more recent National Academies reports: *A Strategy for Research in Space Biology and Medicine in the New Century,*[3] published by the Space Studies Board; and *Safe Passage: Astronaut Care for Exploration Missions,*[4] published by the Institute of Medicine.

As for the connection between scientists and engineers, I was struck at our workshop by how members of the scientific community appeared willing to embrace the idea that the human space flight program can be a contributor to real scientific progress. I think our participants would echo the conclusions of the 1997 report which called for an integrated science program to accompany human missions to the Moon and Mars, as well as the close coordination between human space flight and science program staff in the implementation of an exploration program. Participants at our workshop said many times that the reason the process of setting research priorities by the scientific community has had a positive impact on NASA's science programs is that it creates within the scientific community, a community that in the language of Congress can be considered the constituency of the science programs, a sense of ownership in the program. That feeling of ownership creates what we called a constructive tension between NASA and the science community, which ultimately empowers the program to excel. We observed this sense of ownership to be missing from the human space flight part of NASA, but that does not have to remain the case.

Robotic precursor missions to the Moon and Mars can provide an opportunity to engage this issue of cooperation between science and exploration, develop new technologies for space exploration, and significantly enhance and optimize the scientific return of eventual human missions. A 2002 report by the Space Studies Board, *New Frontiers in the Solar System: An Integrated Exploration Strategy,*[5] highlighted an extremely exciting opportunity for science from the Moon, by making a sample return mission to the Moon's South Pole-Aitken Basin one of its top priorities. By studying the internal structure of the Moon at this location, which is the oldest and deepest impact structure preserved on the Moon, we can investigate how major impacts on the Earth from early solar system space debris shaped the evolution of our planet. The solar system exploration strategy report also identifies important scientific opportunities for the exploration of Mars.

Participants at our workshop argued that precursor missions to the Moon and Mars should seek to move past a previously long-standing dichotomy that has existed between robotic and human space flight over most of NASA's existence. Part of the goal of these missions should be to develop the technology that will allow for the greatest possible human-robotic interaction. Workshop discussions emphasized the concept of synergy—not just complementarity—between robots and humans. We must learn how to best take advantage of the strengths of both, separately and in cooperation.

Further Comments on Science

There are other critical research challenges which deserve equal attention and consideration in addition to the biological and physiological questions I mentioned. Specifically, I refer to two issues highlighted in our 1997 Human Exploration report: (a) the characteristics of cosmic-ray particles and the extent to which their levels are modulated by the solar cycle and (b) the frequency and severity of solar flares. These issues arise from questions about the nature of the role of the Sun in our solar system and how the Sun creates and controls the environment into which we intend to send astronauts. The recent NRC decadal science strategy for solar and

[3] *A Strategy for Research in Space Biology and Medicine in the New Century,* NRC Space Studies Board, 1998.

[4] *Safe Passage: Astronaut Care for Exploration Missions,* Board on Health Sciences Policy, Institute of Medicine, 2001.

[5] *New Frontiers in the Solar System: An Integrated Exploration Strategy,* Space Studies Board, 2002.

space physics[6] identified key missions within NASA's Sun-Earth Connections program that are critical to understanding these fundamental processes and consequently to understanding the volatile space environment. That report recommended that the Sun-Earth Connections program of NASA be charged with, and provided the resources needed for, developing a predictive understanding of the Sun and the space environment it controls. I would urge you to carefully consider the impact of any prioritization that would hinder or delay the development of our understanding of and our ability to predict the space environment.

A Lack of Balance in the Science Programs

It was the opinion of many at our workshop that the science road maps, decadal strategy surveys, and mission plans in astronomy and astrophysics, solar and space physics, and solar system exploration, which have been so carefully developed by scientists and engineers in the external community and in NASA, and NASA's careful attention to these details in execution of its programs, have resulted in science being NASA's greatest current strength. In fact, since the Apollo era came to a close one might argue that NASA's science efforts have been responsible for a major fraction of the Agency's greatest successes. The pertinent question then is: Can NASA preserve the strengths of its science programs and at the same time energize a new human space flight program that seeks to include the science of exploration as part of an overall new thrust for the agency?

This is, of course, a question of balance—balance between a new exploration priority and continuing successful science programs. I would encourage you to consider whether or not the science disciplines have been divided unnecessarily into those that are *perceived* as essential for exploration and those that are not. Our reports argue that the sun and the planets and moons of the solar system are all equally worthy of exploration. They also suggest that research to study both the origins of planetary systems and life and the structure and evolution of the universe are highly important.[7] In Earth science, NASA has a responsibility under the Space Act and its amendments to use its capabilities to understand our home planet and predict its future. While NASA may now have a priority to explore, I would expect that it still also has the responsibility to deliver to the policy makers and the public a sufficient understanding of how we can be good stewards of our planetary home.[8]

How to Move Forward

The matter of balance between new exploration priorities and science opportunities, between new priorities and responsibilities, is very difficult to tackle. I believe the best way to approach this matter, as is emphasized in our workshop report, is to move forward on the human exploration front at a deliberate pace. Our workshop discussions embraced the idea that NASA should pursue a long-term goal via a series of small steps, and they identified *learning* as *the* critical factor that should drive implementation decisions.

There are several subjects about which we need to learn more. We must learn about the technology we will employ in this endeavor. We must learn more in several areas before we can be sure we have minimized the health risks to astronauts. And all of us, the scientific community, NASA, the Congress, and the Nation as whole, must learn how to organize our space program to engage this effort. The workshop report describes concerns that the infrastructure of our space program was formed and sized to support Apollo and it asks "Is the current infrastructure properly configured for a bold initiative?" The report notes that the space program workforce, in the broadest sense, is aging; the attitudes seem risk averse; process seems more important than ingenuity. Can this mind-set be changed? An aging workforce and infrastructure is also a feature of the space science community. Where are the bold new minds that will lead us into the future?

Finally, there is the matter of cost. A sense at the workshop was that it is too premature to estimate how much an exploration initiative would cost—exactly because we have a great deal to learn and because our past experiences have told us that we should be careful in estimating costs too early. This is at the heart of why our participants emphasized a deliberate approach—we should identify critical research and technology development issues and devise, even at this early time, some

[6] *The Sun to the Earth—and Beyond: A Decadal Research Strategy for Solar and Space Physics,* NRC Space Studies Board (2002).

[7] The relation of this research to exploration in its broadest context is addressed in *Astronomy and Astrophysics in the New Millennium,* National Research Council (2000) and *Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century,* National Research Council (2000).

[8] The importance of NASA's Earth science program is addressed in *Assessment of NASA's Draft 2003 Earth Science Enterprise Strategy, NRC Space Studies Board (2003).*

kind of roadmap for progress in those areas. We must also examine the full breadth of NASA's science programs to determine what research already *underway* may contribute to that progress; what research is currently *planned* that may contribute to that progress; and what *new* research is necessary, and we must support them all with the resources necessary to achieve success. Only through this balanced approach, with roadmaps for technology development and scientific progress that are related to each other and flexible enough to adapt to change and to learning can we have a guidepost against which we measure our progress, articulate our successes, and identify our next steps.

This approach to success through a series of individual steps implies a kind of "go-as-you-pay" approach to exploration to allow for affordable and flexible exploration that changes in response to learning. In this sense then, go-as-you-pay is complemented by the practice of pay-as-you-learn.

Conclusion

In closing, Mr. Chairman, I would like to again thank you for inviting me to testify today. I would be happy to address any questions you and the committee may have about our report or the discussions that took place at our workshop. A renewed opportunity for human exploration in the solar system creates an exciting moment in our nation's history. I can tell you that there is indeed great excitement in the space community, which I believe is reflected in our report. I think further that the leaders of the scientific community may be ready to stand up and say "we believe this country should invest in this activity, and we are ready to make the case to the world that this is a valid use of this nation's resources." I am hopeful that we as scientists are ready to engage this process actively to help guide its implementation and direct it toward success.

NRC Space Policy Workshop Participants

November 12–13, 2003

PANELISTS

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Robert Frosch, Harvard University
Riccardo Giacconi, Johns Hopkins University and University Research Associates
Noel Hinners, Lockheed-Martin (retired)
Wesley Huntress, Carnegie Institution of Washington
Thomas D. Jones, Consultant
Todd R. La Porte, University of California, Berkeley
John Logsdon, George Washington University
Richard Malow, AURA
Howard McCurdy, American University
Norman Neureiter, Texas Instruments (retired), Department of State through September 2003
Mary Jane Osborn, University of Connecticut Medical School
Robert Richardson, Cornell University
Edward C. Stone, California Institute of Technology, U.S. Representative to COSPAR
J.R. Thompson, Orbital Sciences Corporation
Albert Wheelon, Hughes Aircraft Company (retired)

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Michael H. Freilich, Oregon State University
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Tamara E. Jernigan, Lawrence Livermore National Laboratory

Margaret G. Kivelson, University of California, Los Angeles
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Harry Y. McSween, Jr., University of Tennessee
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Donald L. Cromer, United States Air Force (retired) and Hughes Aircraft Company (retired)
Dava J. Newman, Massachusetts Institute of Technology

INVITED GUESTS

Bill Adkins, House Committee on Science
Marc S. Allen, NASA Headquarters, Office of Space Science
Andrew Christensen, The Aerospace Corporation, Chair, Space Science Advisory Committee
John Cullen, Senate Commerce Committee
Gerhard Haerendel, International University, Bremen, ESSC Chair
John Mimikakis, House Committee on Science
Richard Obermann, House Committee on Science
Jean-Claude Worms, European Space Science Committee

BIOGRAPHY FOR LENNARD A. FISK

LENNARD A. FISK, Chair of the Space Studies Board of the National Research Council, is the Thomas M. Donahue Collegiate Professor of Space Science in the Department of Atmospheric, Oceanic, and Space Sciences at the University of Michigan. He is an active researcher in both theoretical and experimental studies of the solar atmosphere and its expansion into space to form the heliosphere. He heads the Solar and Heliospheric Research Group, which develops new theoretical concepts and models, analyzes data from the ongoing Ulysses, WIND and ACE missions, and which constructs new flight hardware for upcoming missions such as the MESSENGER mission to Mercury. From 1987 to 1993, Fisk was the Associate Administrator for Space Science and Applications and Chief Scientist of NASA. In that position he was responsible for all of NASA's science programs, including space science, Earth science, and microgravity life and physical sciences. From 1977 to 1987, Fisk served as Professor of Physics and Vice President for Research and Financial Affairs at the University of New Hampshire. Concurrent positions include Chairman of the Board of Trustees of the University Corporation for Atmospheric Research, member of the Board of Directors of the Orbital Sciences Corporation, and co-founder of the Michigan Aerospace Corporation. Fisk is a member of the National Academy of Sciences.

DISCUSSION

Chairman BOEHLERT. Thank you very much.

And Mr. Augustine, I note that the hour has arrived; you must depart pre-arranged. We have got your number. We will be calling. Thank you very much, sir.

Mr. AUGUSTINE. Mr. Chairman, I apologize. I would be happy to take questions for the record, if you would like.

Chairman BOEHLERT. Thank you so much.

Mr. GORDON. Mr. Chairman, if I could, let me just—I would like to publicly thank you, Mr. Augustine. Your 1990 report really is the benchmark for any kind of NASA oversight. All more recent studies and discussions about problems there, the bottom line, they go back and say, "Well, the Augustine report predicted it and told

us what to do." And it was just a very good piece of work, and thank you for what you have done for us.

Mr. AUGUSTINE. Well, thank you. I had a very good group of people to work with.

ROLE OF HUMAN SPACE FLIGHT IN NATIONAL SCIENTIFIC GOALS

Chairman BOEHLERT. Thank you very much. In his testimony, Mr. Augustine and also Dr. Griffin, pointed out that we were about establishing priorities. And we are not looking at an investment in science in comparison to what we might derive from an investment in cancer research or the necessity for investing in low-income housing for the poor or prescription drug benefits for the elderly. We are looking at this as part of our investment in science, the broad category. And just let me say my strong feeling, I think it is shared by others on this committee, that a society unwilling to invest in science and technology is a society willing to write its own economic obituary. So we are looking in the broad category of science, and then we are trying to determine the impact of this initiative on science. And then NASA is a subset of that, and a subset of our investment in NASA is human versus unmanned. And so we are trying to get answers to some very specific questions involving costs and risks, answers that are not easy to come up with. But I appreciate everything that you have presented so far. And we will go right to the questions.

Let me start by seeing if I can point out some areas where there appears to be agreement within the panel. The main reason to have human space flight programs are the intangibles. Human space flight can obviously contribute to goals like advancing science, but the extra benefit for science is not so great to be a sufficient rationale in itself. Secondly, the most serious hurdles to having humans do more in space are the physiological impacts of spending a long time in space, particularly those caused by radiation. We have quite a bit of work to do before we fully understand those effects and what to do about them. And Dr. Young, you focused on that. And NASA can't undertake this mission by doing things the same old way; new ideas are needed, especially ways to engage more entrepreneurs in the process. Is there any disagreement with those basic statements?

Dr. Fisk.

ROLE OF ROBOTS IN THE HUMAN EXPLORATION OF SPACE

Dr. FISK. If I may, there is a nuance on the first one that somehow science and humans—the human role is not so much to conduct science, if I am following you, but to, in fact—for the intangible benefit. I believe that there is an opportunity here when we—you know, if you ask yourself—we put these vehicles on Mars, for example. Well, they are controlled by humans, and they did the exploration, but the humans were in Los Angeles or Pasadena. Will there be any—well, it might have been better if they were closer together, you know. And so the—and yet—so you would have humans and robots both doing the exploration: the humans assisting the robots, the robots assisting the humans. But as we move forth

with the real exploration initiative, I would argue that the humans—that it is a legitimate form of science and that the human presence there has a role in using the human mind, the ability to adjust to serendipity, the ability to solve problems——

Chairman BOEHLERT. And is that, in and of itself, sufficient rationale to justify this program and the impact it will have on other programs and other areas of science? I guess that is the general point I am trying to get at.

Dr. FISK. Yeah, I think you need to do—I mean, the question is what is the—if you ask yourself what is the optimum means to explore a planet like Mars. I would put the—eventually, I would put the humans closer to Mars.

Chairman BOEHLERT. I understand that, but then we have to look at the cost and risk factor, and we have to factor that in.

Dr. FISK. Of course. Of course.

CONCERNS WITH THE MOON AS AN INTERIM STEP TO EXPLORING MARS

Chairman BOEHLERT. And the impact on the other areas of science. That is the key thing.

You know, the other day, I met with Dr. Steven Squyres of Cornell, and he has thrilled us all with his Mars rover missions. It was really exciting to talk to him, and I could have stayed for hours on end. He raised a concern about using the Moon as an interim step to Mars. And Dr. Shirley, I am interested in your observation on this, you referred to it in your testimony. He pointed out that landing on the Moon is different from landing on Mars because of the Martian atmosphere. His concern was that as money got tight, and inevitably it will, all of the elements of the lunar program that would actually contribute to preparing for Mars might get squeezed out, leaving a program that wouldn't get us much beyond where we were in 1969. He didn't oppose going to the Moon, by the way, but he did harbor that concern, and I think it is a legitimate concern. Would you comment on that? And what elements have to be in the lunar program to ensure that it gets us farther? Dr. Shirley.

Dr. SHIRLEY. I think Steve is absolutely correct. And my big concern is, having—excuse me, having worked in this process for years and years, when you start building infrastructure, the infrastructure takes on a life of its own. So we built the Shuttle, which was going to be, you know, the ultimate vehicle, but of course, it was starved for funds, so it was never fully reusable. It continued to be very expensive. It has never lived up to the hype, frankly, that was used to sell it. Similarly with the Space Station. Back—I was on the Space Station from '80 to '84, and the fact was that it was trying to be all things to all people. It was trying to be, and it turned out to be, a big jobs program and then an instrument of international policy and so on, and it is still absorbing money. My fear is the same as Steve's that: as we go to the Moon, we are going to want to put infrastructure up there. My contention is that there is almost no commonality between Mars and the Moon that is going to justify the vast expenditure that it would take to make the Moon a viable stepping stone. The President's vision calls for using resources, and there are no resources on the Moon, that I can see, that are going to be of any value for going to Mars. So I think——

Chairman BOEHLERT. Thank you.

Dr. SHIRLEY.—it is a diversion.

Chairman BOEHLERT. Dr. Griffin, would you care to comment?

Dr. GRIFFIN. Thank you. This is, unfortunately, one of those topics where Donna and I, who are long-time colleagues, disagree. I think there are direct and less tangible benefits to using the Moon on the way to Mars. The direct benefits are very simple. I am an engineer. I am not a scientist. I am not, at all, dissuaded by the fact that Mars has a small atmosphere and the Moon does not. I believe there is far more common about the engineering design of a lander for the Moon and Mars than there are differences. And the addition of an aeroshell as part of a lander system on Mars, I think, should not be allowed to sway the discussion away from the immense commonality, which could, and should, exist if the design were done properly.

Secondly, I think the value of being on the Moon on the way to Mars, even if Mars is the more interesting planet, and I agree that it is, the value of being on the Moon is learning how to live on another planetary surface only a few days away from home when we have one man month of total experience of doing that. And it was, you know, 30 years ago plus at this point, and will be way in excess of that by the time we go to Mars. I think it is an act of technological hubris to assume that after five decades of not venturing beyond Earth orbit we are going to go direct to Mars. I just would be opposed to that.

Dr. YOUNG. I agree with Mike.

Chairman BOEHLERT. Okay. Thank you. But——

Dr. GRIFFIN. And by the way, I agree completely with his earlier comments on parceling science out according to whether or not it is exploration science or other kinds of science. That is among the sillier things we have heard recently.

Chairman BOEHLERT. My time has expired.

Mr. Gordon.

LESSONS LEARNED FROM THE SPACE EXPLORATION INITIATIVE OF 1989

Mr. GORDON. Dr. Griffin, you were directly involved in President George H. W. Bush's space exploration initiative in the early 1990s. And I hope you could give us some advice as to what was the major reason that the '89 space exploration initiative failed to win public and Congressional support and how different is the situation today?

Dr. GRIFFIN. Looking back on it from a perspective of 15 years, I think the major reason was that completely inappropriate cost estimates were published and publicized before we really knew what the architectures were going to be or should be. They became nationally recognized as the $400 billion space exploration initiative when there was never any actual specific content ascribed to that number. But that number, on the face of it, was unacceptable.

The second thing that we failed to do, or that the people failed to do, was to recognize and solicit the—recognize the need for and solicit bipartisan support of the effort. No exploration program can be accomplished within one president's tenure, certainly not even within a senator's tenure. We will have many changes of adminis-

tration. If we subscribe to exploration as a proper goal of the civil space program, it needs to be thought of the way we think of having a navy. We do not decide at every change of administration whether we will continue to have or not to have a navy. Minor course corrections are implemented, depending on the political necessities of the time and the strategic necessities of the time, but we don't debate whether we will have a navy. We need to adopt that same view with regard to NASA and space exploration.

Mr. GORDON. Thank you. That makes a lot of sense.

SHIFTING NASA MISSIONS TO OTHER AGENCIES

Some have suggested that the way to make the space exploration affordable is to shift some of NASA's existing activities to other agencies. And presumably, the responsibility for paying for those activities would also be shifted to other agencies. For example, some have suggested that shifting NASA's aviation activities to the FAA. Others have said NASA should eliminate its Earth science program and shift them to NOAA. And I would like to get the general Committee's—or panel's suggestions as to whether you think that is a reasonable approach. Anybody just go ahead and start.

Dr. SHIRLEY. I think, for instance, before we do that, we need to look at what the missions of those agencies are, and those agencies would have to have their missions adjusted. For instance, the FAA's mission is not to develop technology. So if you are going to transfer it, you have to make sure that the FAA is prepared to take on that mission, and it is not clear at all that it—I mean, whether its infrastructure and its bureaucracy and all of that would be adequate for it. If you are going to shift Earth science to NOAA, same thing. NOAA is an operational agency, not a development agency. So it is possible to do it, but it is going to be a difficult process.

Mr. GORDON. Anybody else care to comment?

Dr. YOUNG. Yes, speaking only about the human health issues, and the obvious question would be to what extent should the National Institutes of Health be responsible for them, I think it is worth pointing out that there has been a successful history of cooperative endeavors, including the very successful Neurolab mission, in which the NIH and NASA worked together on them. However, I think, in my opinion, it would be a mistake to get out of the life sciences business in NASA and shift it all to NIH, because I think the specialization that has been acquired, both in the outside university community and inside the agency, could not be replicated within the NIH.

Mr. GORDON. Another quick couple of just—does anybody have a differing opinion?

Dr. FISK. The NOAA/NASA relationship is a very healthy one. I mean, they—but, as Dr. Shirley mentioned, I mean, there is a very different mindset in the agencies as to what their role is. I mean, NASA's role has been research, and NOAA's role has been on the operational side. The planet needs taken care of, and it needs to—we need observations. We need data systems. We need research on how it is, in fact, progressing and what we, as humans, are doing to it. And this is a role that NASA is uniquely capable of doing. I mean, it is the space agency. I mean, NASA builds many of NOAA's satellites to start with. I mean, this is not, you know, as

if an agency like NOAA, you know, simply takes this whole responsibility on and can expect to be able to accomplish it.

Mr. GORDON. Thank you. And this could wind up being a threshold question of going through, and your insight was helpful for me. Thank you.

Chairman BOEHLERT. The Chair of the Subcommittee on Space and Aeronautics, Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much.

EXPECTATIONS FOR THE INTERNATIONAL SPACE STATION

This is very perplexing, having been here 16 years now and following all of these debates about Space Station. I am certainly hopeful that what we are talking about now, which is, of course, a next step, doesn't turn out as disappointing as this step has been. The Space Station—Dr. Shirley, I guess you have described it as a jobs program. And it—to some degree, we have to admit that it was a transition out of the Cold War for the aerospace industry, at least a lot of us saw that. It was a means of keeping the aerospace industry's infrastructure in place. But do—I would just like to ask the panel that—were you all aware that there was going to be as limited, of say—as limited a product or output of the Space Station as we now are being told? I mean, apparently what you are telling us now, what we are exploring now, is Space Station is simply going to be a training ground for further exploration so we can find out about how the body works so that we can go on and—to further space exploration. For the last 10 years, we have been told Space Station's scientific experimentation was going to be so much greater. It was going to change all of humankind for various cancer research and all sorts of other things. Maybe you could comment. Is this—we now are—we are learning—are we now just saying Station is just going to fulfill that mission? And if that is so, how long have we known that that is how limited the mission would be?

Dr. YOUNG. Well, like Dr. Shirley, I was involved in almost all of the early external advisory committees on Station, and I shared the hopes that you reflected, Mr. Rohrabacher. I think it is much too early to write off the Space Station. This is a project that is still——

Mr. ROHRABACHER. Okay.

Dr. YOUNG.—under construction. It is unfair to expect the kinds of productivity that you would expect of a fully crewed, fully completed station, let alone the fact that we currently don't have ways of getting our supplies up and new equipment up. I mean, think back to the situation of the Hubble Space Telescope in those bad days when we found out the mirror was flawed. Who could have predicted the string of successes that HST has produced? I think that we——

Mr. ROHRABACHER. Well, I think that that was very predictable. No, I disagree with you. I think it is very predictable if we had corrected the Hubble Telescope that they would have done what we have done. And I am working with my fellow colleagues here to make sure that we continue to make sure the Hubble Telescope is at least giving us some pay back. That is one of the few things we have invested in that does have a great deal of scientific pay back.

But I am happy to hear you suggesting that maybe some people are being a bit pessimistic as to what can come out of Station.

Dr. SHIRLEY. If I could comment on——

Mr. ROHRABACHER. Yes.

Dr. SHIRLEY. The initial vision of Station was to be all things to all people. And it was sold that way, and it was sold to the science community that way. And it was a very deliberate strategy. I saw maps that NASA had of how many Congressional districts would have jobs in them and that they were shown to try and sell them.

Mr. ROHRABACHER. I don't know of any of them in my district.

Dr. SHIRLEY. Absolutely. And the fact is that when you build such huge expectations and—by promising everything to everybody, it is a recipe for disappointment, and that is why I am afraid of the lunar thing being exactly that. And I think personally that the Station can be most valuable in exploration for exactly what Dr. Young was talking about.

COSTS OF MOON AND MARS MISSIONS

Mr. ROHRABACHER. Well, if I might mention that the reason why the President's stepped approach seems to me to be the most realistic is just for the reason you just stated, although you come to a different conclusion, and that is people will then realize the benefit of making these steps as we go along as compared to trying to sell the public on something that is as expensive and way out as going to Mars immediately would be. The public may lose some faith or some hope, and that comes to my question. How long will it take us before we can—if we went straight to Mars, how long are we talking about, at what price versus the stepped approach? If we go to the Moon and then to Mars, what are we talking about? What time sequence? Just right down the panel would be okay for predictions on that. Dr. Griffin, do you have any idea on that?

Dr. GRIFFIN. I think I need to pass on that. I am not sure I——

Mr. ROHRABACHER. Okay.

Dr. GRIFFIN.—understood the question.

Mr. ROHRABACHER. The question is how long will it take us just to go to Mars, what cost. And what, then, are we predicting in terms of what you would predict it would take us to go to the Moon and then to go to Mars and the difference between the two?

Dr. GRIFFIN. The—I think the problem is how much money do you want to make available, because there is a coupling between the money which is available and the time that it is going to take. I believe that the first expeditions to Mars should be accomplishable within an amount of funding approximately equal to what we spent on Apollo. And I have recently——

Mr. ROHRABACHER. Which is?

Dr. GRIFFIN. In today's dollars, about $130 billion.

Mr. ROHRABACHER. Okay.

Dr. GRIFFIN. Certainly, that would envelop it. I believe that it should be possible to return to the Moon for in the neighborhood of 30 billion in today's dollars, and those are both fairly comfortable amounts. I have recently participated in a NASA advisory panel where we have been examining the costs and benefits of human space flight, and the $130 billion figure for going to Mars is very compatible with what we have seen in that study.

Mr. ROHRABACHER. And can we be on the Moon in 10 years?

Dr. GRIFFIN. Easily. It is—it requires a decision to do so and to allocate the money.

Mr. ROHRABACHER. So $30 billion and we can go to the Moon in 10 years?

Dr. GRIFFIN. I believe that is exactly correct.

Mr. ROHRABACHER. And $130 billion to go to Mars would be in 20 years?

Dr. GRIFFIN. I—if you decided to go to Mars, you could be there in 10 years. You would have to decide to do it——

Mr. ROHRABACHER. Okay.

Dr. GRIFFIN.—and to allocate the money, but I think that is the level of resource commitment——

Mr. ROHRABACHER. Mr. Chairman, if you would indulge me just to get the——

Chairman BOEHLERT. Well, I am anxious to hear from all of the witnesses. That is a very good question on that.

Dr. SHIRLEY. I think Mike's numbers are pretty good, provided that we do the stepping stone to the Moon and we don't stop there and we don't start building infrastructure and we don't start doing what we did with Space Station.

Mr. ROHRABACHER. But you say——

Dr. SHIRLEY. If we go to the Moon and then right on to Mars, then I think——

Mr. ROHRABACHER. $30 billion and 10 years to go to the Moon——

Dr. SHIRLEY. Those are not bad numbers. I mean——

Mr. ROHRABACHER. Okay, Dr. Shirley.

Dr. SHIRLEY.—50 percent or whatever.

Mr. ROHRABACHER. Okay.

Dr. YOUNG. I do not have the figures to either agree or disagree with Dr. Griffin. I do, however, fear that once committing to go back to the Moon, we will never make it to Mars.

Mr. ROHRABACHER. Okay.

Dr. FISK. Norm Augustine had a sentence that said, you know, we should "pay as you go." If you don't—I would like to have one that we should "learn as we go." Decide on these answers, you know, how fast you go back to the Moon, how much does it cost you whether you go to Mars is going to depend on each incremental step that we go. We don't know how to send people to Mars at the moment. We may know technically how to send people to Mars, but the physiological issues that are identified do not have immediate solutions today that have to be identified, proven out, and solved. The Moon appeals to me for the simple reason that we have an opportunity to go there and try out some of our technical solutions on the way and decide whether they are going to be adequate. If you pull the plug and you go to Mars, you know, hitting the reverse is a little hard, so you have to go there, land, and come back, and that is your only option. And so the cost of this thing should not—and I don't think we should try to find a number. We should try and find a number of what are the steps that we should take on which we—that we learn something and we adjust our program to take the next logical step and incrementally walk through those steps.

Mr. ROHRABACHER. Well, you know, cost is very important to us, because we have to go to the taxpayers and get the money. But would you say we can do it in 10 years for $30 billion?

Dr. FISK. I have not a clue, and I don't think any of us should have that clue.

COSTS AND RISKS OF HUMAN SPACE FLIGHT

Chairman BOEHLERT. Let me just ask you—your time is expired, but I wanted to amplify that. Dr. Griffin, that is just talking about getting from here to there, your cost estimates. It doesn't factor in all of the necessary research on physiology and everything else, does it?

Dr. GRIFFIN. You know, speaking—I am sorry——

Chairman BOEHLERT. Those are cost estimates, yeah.

Dr. GRIFFIN. I differ from some of my panel members. I think the issues involve—physiologically, of course, going to the Moon, is not, at this point, an issue. The issue might arise in how long you can stay, and we don't know that until we see. In terms of going to Mars, the exposure to zero gravity is within the experience base, easily, that has already been undertaken by people, and they have survived the experience. No one argues that degradation doesn't occur.

Chairman BOEHLERT. Um-hum.

Dr. GRIFFIN. No one argues that they will remain in perfect health, but so far, the ability of the body to heal itself after experiencing those exposures has been demonstrated.

Chairman BOEHLERT. That is not the Russians' experience, is it?

Dr. GRIFFIN. Ken Bowersox flew six months on Space Station, endured a high gravity ballistic reentry, because the Soyuz malfunctioned and went to its backup mode, landed out in the wrong place in Russia in the middle of the steps. He and his crewmate crawled out of the Soyuz, pitched a tent by themselves, and waited 24 hours to be picked up.

Chairman BOEHLERT. He didn't have exposure to radiation.

Dr. GRIFFIN. He did, actually, have substantial exposure to radiation. The radiation flux on—of high-energy protons is about 25 percent on the Space Station per unit time of what it would be in deep space.

Chairman BOEHLERT. 25 percent?

Dr. GRIFFIN. About 25 percent of the radiation flux to Space Station is heavy ion particles as would be——

Chairman BOEHLERT. But isn't that a big difference?

Dr. GRIFFIN. It is a difference. It is significant. I am not saying that it is not. I am saying that the crew crawled out by themselves in an emergency mode, pitched a tent and waited to be picked up. I think landing on Mars, after a six-month journey, would not be more arduous. I believe that if—this is a profound philosophical difference. It is not one of engineering. I certainly do not oppose, in fact, strongly support the biomedical research that Dr. Young and Dr. Fisk would do, but it is an adjunct to and can be done in parallel with human exploration. It is not a gate. If we expect to explore and not take risk, we are leading ourselves down the wrong path.

Chairman BOEHLERT. I would agree with that. You can not eliminate the element of risk. No doubt about that. But six months to get there and six months to get back——

Dr. SHIRLEY. Actually, it is six months to get there and two years to get back. It is, roughly, a three-year round trip.

Dr. GRIFFIN. That does not have to be the case, and it depends strongly on the trajectory selected and the technologies used.

Dr. SHIRLEY. Well, if you go nuclear, yes.

Dr. GRIFFIN. And the architecture that is used.

Dr. SHIRLEY. That is not cheap, either.

Chairman BOEHLERT. Yeah.

Dr. GRIFFIN. There are an enormous amount of—number of scenarios, which have been advanced, used, and——

Dr. SHIRLEY. And that is exactly why I think we need to have a dialogue about what the right thing to do is rather than just plunging into we are going to do this exactly the way we have done it before.

Chairman BOEHLERT. And that is exactly why we have experts like you that we appreciate so much being facilitators for this committee, because these are the questions we are wrestling with every single day. And——

Dr. GRIFFIN. I, too, want to have that dialogue, but I don't want to start out assuming that it is three years round trip to Mars for any possible architecture we could advance. I think that would be wrong.

Chairman BOEHLERT. But then you have to talk about the costs for advancing the architecture, and that is the point that Dr. Shirley makes, so that adds to the dilemma we face. And Dr. Fisk, I couldn't agree more that we need some benchmarks that if we get to this point and spend this much, we hope to achieve this much, and if we decide at that time to go further and it is too expensive to go further, we will stop and not have that money wasted, wisely invested, because we have gained something from it.

Dr. FISK. The incremental approach is—has got to be the way to do this. I mean, you—this is not—I mean, the President said something I—you know, I very much agree with this. This is a journey. This is not a—you know, a short task and——

Chairman BOEHLERT. It is not a trip; it is a journey.

Dr. FISK. Yeah, whatever it was.

Chairman BOEHLERT. Yeah.

Dr. FISK. And the—and because—I think we have to think of it in both of these time scales. You know, it is simply incrementally marching forth——

Chairman BOEHLERT. I have got the exact words: "It is a journey, not a race."

Dr. FISK. Sorry.

Chairman BOEHLERT. And with that, speaking about a journey, Mr. Lampson of Texas.

Mr. LAMPSON. Thank you, Mr. Chairman.

More reason why we could actually use the Space Exploration Act as a vehicle to achieve some of what we are talking because it does, indeed, set out a long-term journey.

NEW PRIORITIES FOR SPACE STATION RESEARCH

Dr. Young, former Senator and astronaut John Glenn recently testified before the Aldridge Commission, and at that time, he criticized the plan—additional—planned additional cutbacks in the International Space Station program, saying: "We have projects that are planned or in the queue now, projects that people, academics, laboratories, and companies have spent millions of dollars to get ready that pulls the rug out from our scientists who have placed their faith in NASA and our scientists within NASA who devoted years and years to their work." I notice that in your written testimony, Dr. Young, you also questioned the wisdom of the planned cutbacks, stating, and this is your quote: "The proposal to limit ISS research to the impact of space on human health and to end support for other important microgravity science and space technology seems short-sided, and I strongly believe in the scientific and technical value of a permanent presence in space." Would you please elaborate on why you feel the proposed approach would be short-sided?

Dr. YOUNG. First of all, I am in complete agreement with the quotation from former Senator Glenn, I only read the newspaper reports of it. We will need a place to do microgravity research, not only for trying to understand what the basic physiological problems are with long duration flight, but for the entire range of fascinating issues about the role of gravity in biology, in physics, and in technology. We know a lot about 1 g. We know a little about 2 g. We know an increasing amount about 0 zero. We know nothing—except for a few men on the Moon, we know almost nothing about the effects of levels between 0 and 1 g. There is no reason to think that it would be a linear curve that you go through one. The Space Station is the place to do this research to understand how to grow crystals, to get away from sedimentation and convection. It is the place to go and understand the physics of the basic fluid physics that goes on in microgravity. If we didn't have a Station operating, we would have to come back and build a new one, so to my mind, it is extremely short-sided to let go this very expensive, still developing project that we have, despite all of the shortcomings that have been referred to with it.

Mr. LAMPSON. Dr. Fisk, you—the Space Studies Board, I reference the range of basic and applied microgravity research disciplines, do you want to make your comment?

ROLE OF THE SPACE STATION

Dr. FISK. Let me make a couple, and I am a—in addition to being chair of Space Studies, where I am a veteran of the Space Station wars when I was on the NASA side of this thing. There are two things that I think are important here. I—this is—maybe this is a personal opinion. The Station has lacked a purpose, in my judgment, up until now. The science community, as a whole, has taken an attitude to all of this, with this thing, that if it existed, we would try and do something with it. And there are communities that are very passionate about this, but the broad science community has been reluctant on what the proper role is of this thing.

NASA conducted a REMAP exercise not so long ago in which it really asked what should be done on the Space Station. What is in the interest to really do this thing? And the plans, at the moment, are quite consistent with that REMAP activity. And the idea is to, as you say—this is—here is a real purpose to this thing: qualify humans for space. And there are lots of dimensions to that. It is not just, you know, the human physiology. It is how do you, you know, do fluids in space. You know. How do you deal with combustion in space? I mean, there are lots of things that a permanent presence in low-Earth orbit, in zero gravity, will be essential if we are, in fact, going to extend the human presence beyond low-Earth orbit. And I think that, you know, as a scientist in the general sense, it is not my field of research, but being able to say, "This is why we have the Space Station. This is why this investment has been made, and this is how we are going to use it," is one of the few times that—in all of those veterans of—all of those years of being a veteran in this when I felt comfortable thinking that this investment was, in fact, worthwhile.

Mr. LAMPSON. I am going to attempt to ask a question that is very—Dr. Young?

Dr. YOUNG. I just wanted to add, briefly, that NASA, in its wisdom, has—and I truly mean in its wisdom, has suggested that the Space Station purpose be implemented through the development of an International Space Station Research Institute. Now that—those plans have been put on hold with this new vision, but many of us feel that that is the way to go to get the entire scientific and technical community involved in directing it.

Mr. LAMPSON. Dr. Griffin.

Dr. GRIFFIN. I will try to be brief, thank you.

I think the quarrel with the Space Station is not over what it does, but what it costs and what it has cost. Because it has cost so much and taken so long and in—just in general been so poorly executed as a development program, it needs, in order to justify that, to be able to say that it has accomplished things that it can not accomplish and never was intended to accomplish. Had we put a space station up having, you know, the volumetric equivalent of a couple of Skylabs docked nose-to-nose with the power array that it had, we would have been able to do microgravity research, materials processing research we would have been able to do very nearly as much as we expect to do on International Space Station at a tiny fraction of the cost, and everybody would regard it as having been a great victory to obtain those results for that cost. The path we went down is what is flawed, not the results that we are trying to obtain.

Chairman BOEHLERT. Thank you very much.

The gentleman's time has expired.

Mr. LAMPSON. Thank you, Mr. Chairman.

Chairman BOEHLERT. And we want to make sure we go down the right path, the correct path, with this proposed initiative, and that is why we are spending so much time on it, and that is why we appreciate your input.

Dr. Ehlers.

Mr. EHLERS. Thank you, Mr. Chairman.

I have a number of questions, but let me first of all comment, since everyone is estimating what it is going to cost to go to Mars, I would agree with $130 billion one way. I think we need to—I am suggesting we look for volunteers who would want to make a one-way trip. It would certainly save a lot of money. But I am convinced it would cost considerably more if we really are serious about bringing a human to Mars and bringing them back home. I don't want to get into the debate now, but I have substantial reasons for believing that.

FUNDING PRIORITIES OF SCIENCE OR EXPLORATION

What I want to get into is the old question of science versus exploration or science versus hardware, if you like. And I am very concerned about what I see happening. I was impressed with Mr. Augustine's comment that astronauts should not be truck drivers; they should be participating in scientific research, bringing equipment to space, fixing equipment in space, and so forth. And it seems to me the Hubble Telescope precisely fits that definition whereas now we see Hubble being canceled, ostensibly for safety reasons, and I think the Administrator is very sincere in believing that it is unsafe. But at the same time, we are going to have to bring Shuttles up to Space Station and back to bring crew up and resupply and so forth. That is just the background for asking, particularly Dr. Fisk first, and I ask the others to chime in. What do you see happening to science, and I am referring not just to space science, but also to the Earth science that is done from space, which has been invaluable? It seems to me, that is going to be shorted if we suddenly decide to put a lot of extra money into the Station, into the Moon, into the Mars mission, and so forth. And once again, science would be left in the dust, and the money would go into exploration and hardware. I would like to see them combined, and I agree with that statement. I haven't seen it happen so far. We will start with Dr. Fisk.

Dr. FISK. This is an interesting discussion for, again, those of us who are veterans of this. For long periods of time, this battle was framed in a—sort of a humans versus—human space flight versus science. And you know, we argued, you know, did the Space Station and the Shuttle take too much resources and so on? And was it taken from the more productive, based on our judgment, science programs? This—today, it is a sort of different story, if you think about it. I mean, actually the space science budget of NASA aggregated, has grown, is actually growing in the President's initiative. And what you see, however, is there is a sort of a science versus science part of this where the science which is directly related to the exploration initiative, particularly the solar system exploration and parts of the Origins Program and so on, are prospering, because they are an integral part of this.

We have introduced a lunar probes program, you know, as a precursor to understand the Moon and the human exploration part. The Mars program has grown and so on. But there are parts of the science program, which have, as a result, been cut. And so you sort of—you know, it is presented as sort of an interesting battle to the scientists, because it is sort of science versus science not science versus the human exploration program. And I think the—you

know, as I tried to say in my remarks, I think that it is important that we don't go there on that science versus science side, because it is not obvious where you want to put the line as to which science is supported—is supportive of the space—of the exploration issue and which is not.

I would argue that Sun-Earth Connections, which was on the other science side here, is an essential component of any exploration initiative. We are sending people out into an environment. We had better understand it and be able to predict it. I would argue that the structure and evolution of the universe is as much an exploration activity as is the Origins program. And so I think I would prefer that they had not gone in and said we have got good science and lesser science in this thing, because I don't think that that is a justifiable position, but it is not science as a whole versus human space flight. One of the beauties of this initiative, to me, is that it is the first time I have seen in the history of NASA that they have really tried to integrate robotic science and human space flight in a synergistic way, and for at least those disciplines that have been judged to be an important part of the science program. Earth science, as I say, is a special issue, because, you know, it is—we could argue that we are exploring our planet, but that is not quite—you know, I don't—I think we simply have to recognize that NASA has a responsibility here that it should not falter on to provide this level of support. I mean, there are many presidential priorities besides exploration, and one of them is global climate change issues and such things as that, and NASA has an obligation to fulfill those, and it has to fit somewhere in this program.

Mr. EHLERS. Any more comments?

Dr. SHIRLEY. Yeah, I would just like to comment that the Hubble Space Telescope—I happen to agree with the Administrator's decision on HST, because I think we could build a robotic mission for less than the cost of a Shuttle launch that could do the repair. We have been building robots that could grapple a spinning satellite since 1986 or '87. I mean, it is not that hard to do. We don't have to have people doing it, and there are reasons of exposure, and so on, for the astronauts.

The other one is—my main concern is that infrastructure will eat science. Infrastructure will eat exploration, and that our passion for infrastructure is—the—NASA's passion for infrastructure is so strong that unless we bring in some outside perspectives—I mean, let us take the space elevator. It may be a completely crazy idea, but shouldn't we at least look at it? I mean, if you made an investment in some alternate way of getting stuff up into space, maybe it would pay for itself. I am not saying it is the right answer, but NASA is not even looking at anything like that, so I think we need to—infrastructure and get to where we want to go and get accomplished what we want to accomplish, and that is going to be really difficult with NASA's current set up.

Chairman BOEHLERT. Thank you very much.

The gentleman's time has expired.

It should be noted that the Earth science project actually would decline through '09, and that doesn't even factor in inflation, so that is a—it is rather a substantial cut in spending for Earth science.

Mr. Gutknecht.

Mr. GUTKNECHT. Thank you, Mr. Chairman.

EFFECTS OF BUDGET CHANGES

Just first an editorial comment. I think, at some point, we are going to have to do a better job, you and us and everybody, of explaining costs and benefits to the American taxpayer. I don't know how long the American taxpayers are going to be paying billions of their grandchildren's money growing more crystals. We have been doing that for a long time, and I am not sure which each iteration of new crystals is really doing, so I—that is an editorial comment. I think we all have to think about talking to our constituencies about, you know, what are the real benefits of this, because this is a big cost.

One of the questions I was going to ask, it is my understanding, as a Member of the House Budget Committee, that the Senate budget resolution endorsed the President's plan but reduced the amount of funding from what the President had requested and essentially said to NASA to move ahead, but go more slowly. What effect do any of you think that that will ultimately have on the long-term goal?

Chairman BOEHLERT. While you are pondering the answer, just let me point out to the distinguished Vice Chairman of the Committee that that is precisely what our mission is right here, self-imposed. We want to find out, as much as humanly possible, within reasonable guesstimates, what the costs will be and what the benefit will be. And that is what the whole drill is about, and that is why we are having distinguished witnesses like you to enlighten us.

Now who wants to go first?

Dr. FISK. Should I try?

Chairman BOEHLERT. Dr. Fisk.

Dr. FISK. As far as the President's initiative is concerned, you have sort of got—you know, if we agree on the goal, what we are trying to do, then you have kind of got three issues: you have content, you have budget, and you have schedule. And if you freeze two of those, you say I like the content but the budget is limited, the schedule is your variable. And you know, the question is: Can you make reasonable progress on this on that sort of a schedule? And the schedule can be negative on something if you can't make progress at all, I suppose. And so I think this is the issue that you face.

You know, if the budget situation of the Nation is such that it is not possible to give NASA the request that it—that the President asks for, then you basically are determining the pace on this initiative, assuming that you agree that the—we have an exploration initiative, we are going to proceed incrementally. To do that, we are going to develop some infrastructure to send humans into space, we are going to use the Space Station to qualify humans, and so on and so forth, then you are setting the pace. At some point, the pace becomes completely unacceptable, I mean, you know, no progress. I mean, we talk—we worry about sustaining this through multiple administrations.

Well, the only way that is going to happen in practical terms is that we have in each Congressional cycle, let us be blunt, some visible signs of progress. If NASA launches something, there is a robotic mission to the Moon, there are robotic missions to Mars, we start qualifying the vehicles, and so on, and that is, to me, the pacing item that whether or not there is within this program there are sufficient resources to make visible signs of progress as you go through it.

Dr. GRIFFIN. I would like to make a comment, also. I think I would certainly be in support of an additional allocation of funds to NASA, but even if that doesn't happen, I think the fundamental argument on the table is what sort of a space program do you want to buy with the money that is currently being made available. As I said earlier, and I will say it again, I agree, and Len and I have had our battles over the years, but I agree completely with what Len has said regarding, you know, reprioritizing what goes on in science. And some of it does not seem to be well motivated. The idea of not understanding, if you will, space weather when we seek to undertake a new voyage—new voyages of exploration in the solar system, it seems fundamentally wrong-headed.

But leaving aside, for a moment, the issues of change on the margin in the science program, the fundamental issue on the table is what sort of a human space program do you want to buy with the money that is being spent on human space flight as we bring the Station to a close and retire the Shuttle? And I think that is the debate topic. I think the goal that the President has proposed is a much better goal or set of goals than those which have been proposed previously.

Dr. SHIRLEY. I don't disagree with the goals. What I disagree is how we are going to go about reaching them, because I am concerned that if we just keep doing what we have been doing for the last 50 years, we will just get more of what we have got, which will not accomplish what Len is talking about. We won't make tangible progress. We will send robotic missions. I mean, we are doing that. Every 26 months there is going to be something new hitting Mars, but making progress in the human arena, for instance, retiring the Shuttle and the current program is retired before they have got even the crew exploration vehicle, and the crew exploration vehicle won't handle cargo. And it—and none of the European or Japanese ones will handle downmass, so you could have an experiment like the Centrifuge up there, and say you need to fix it and you want to bring it down, you can't bring it down, because there is nothing to do that with.

So the approach of okay, this is what we have got and we are going to, you know, go in this direction without looking at any other direction is what my main fear is, because I have seen it happen over and over again.

Dr. YOUNG. I won't give a cost estimate, but I would like to just very briefly return to your editorial comment. Yes, NASA and those of us who work with NASA must do a much better job at communicating to the public. The importance and the excitement, and it is not just growing another crystal. A lot of good material has come out of it. The public, in fact, given the appropriate information, as we know from the Hubble Space Telescope, can get very excited

about such non-trivial questions as where did we come from, where are we going, what were the origins of this universe, what will be the fate of our planet. I wouldn't underestimate them.

Chairman BOEHLERT. The gentleman's time has expired.

Dr. Griffin, let me just point out that NASA has the biggest percentage increase in the non-discretionary, non-security area, and you are asking for domestic. And you are asking—you would like to see an increase, and I can understand that. And there isn't a Committee in this Congress that doesn't have the fluent, skilled people in their disciplines making the same argument. Our problem is where do we get it from and—in relationship to other areas of science. Once again, I am not comparing this to outside the science field, within the science field and within the NASA programs. I think the President was rather prudent in what he called for over the long period and the investment he is asking from Congress and the American people for his vision to be implemented. But money is not easy to come by. And we have to consider all areas of science, and I stress that.

Mr. Feeney.

STUDIES OF SPACE EXPLORATION

Mr. FEENEY. Thank you, Mr. Chairman. Dr. Shirley, I have listened as you have suggested that we have some additional workshops, we review some additional potential for the human space program. You have mentioned, for example, the space elevator. My concern is, though, that while you are basically criticizing this proposal as having tunnel vision or being too focused, my concern is sort of the opposite of yours and that is that we may be ultimately guilty of paralysis by analysis and reanalysis. And I don't think the two are mutually exclusive. We can continue looking at additional opportunities, but the beauty of the President's program is that it is a stepped approach, it is a flexible approach, it does lend itself, as Dr. Fisk suggested, into a "pay as you go" or "pay as you learn" program. And so I would be concerned that we could now, without delay, agree on a first step that could be of huge benefits in the future regardless of what additional opportunities may present themselves as technology advances, as space fiction writers seep into the actual real world development and engineers, like Dr. Griffin, learn about the potential.

But what I am really concerned about and would like to hear you address is that if we are going to go out one more time, because there are libraries full of studies about the potential for human and robotic space flight in the civilian arena, if we are going to go back to scratch, just a study of the studies would take a decade or two. And I would ask if you would comment, perhaps, whether it is not necessarily mutually exclusive to ask some of the probing questions you have asked without stopping in its tracks the space program.

And then secondly, I would like the entire panel to comment on the debate about whether or not the Moon has any worthwhile resources, Helium-3, for example, because I think Dr. Shirley addressed that pretty directly as she is skeptical, to put it mildly, but I would like to hear—and then finally, as you address the—you know, what can we cultivate resource-wise on the Moon, if each of you would say a few words about the fact that there is no ultimate

goal here. The President has stopped the portion of the future book that we are writing at landing a human being on Mars. But he has described this as a journey, and we don't—that is not the end of where history will leave us in space exploration, and we don't know what we will find. We don't know what the technological opportunities will be. We don't know what physiological capabilities will be able to assist humans.

And so Dr. Shirley, if you will start with the paralysis by analysis problem you are proposing, and then if the other commentators will weigh in. Thank you.

Dr. SHIRLEY. I agree with you completely. We don't want to stop what we are doing. I certainly would not say that we wouldn't do the next robotic missions to Mars, that we wouldn't look for water on the Moon and so on. You are absolutely right. We want to keep doing that.

What I am concerned with is that the next big infrastructure step, you know—for instance, the Moon. Let us say we are going to invest a lot of resources in going to the Moon and setting up a base and practicing for Mars, that is going to take a lot of money. My concern is that if we just do it the way we are going to do it, you know, we are going to build a heavy-lift launch vehicle, we are going to—and then we will invest a heck of a lot of money in something, which may have no other use whatsoever, but there are people who want to build heavy-lift launch vehicles.

My only suggestion is that we step back, not from moving ahead and doing things. Let us finish the Station. We owe it to our international partners, if nothing else, to finish the Station. Let us start looking at launch vehicles and things. But before we take that big investment into the next X–33, which we spent a billion dollars on and then canceled because we were expecting too much of the technology or before the next thing we do, which I was just talking to Norm Augustine about, the next thing we start and then cancel, let us bring in some fresh perspectives, not to stop what we are doing, but to think about where we are going to go in the future. And frankly, you know, there is business getting involved in this right now. How can we exploit that? You know. We are not thinking about that at all. NASA isn't thinking, even remotely, about how to really form a partnership with the private launch vehicles. What are we going to do about China? You know, the first person on the Moon could be Chinese. The first person on Mars could be Chinese. Do we want that? Or do we care? You know. I think we ought to address those kinds of issues.

So I think you are absolutely right. We need to continue what we are doing. We need to take those steps and not stop, but we need to think of when we take that next big step, how do we do it. And lunar resources, Helium-3 is fine. There is Helium-3 on the Moon. We found it. No problem. But how do you mine it? You are going to have to boost out of Earth's gravity well a heck of a lot of mining machinery in order to scrape it off of the surface. Then you are going to have to somehow burn it in a fusion reactor, and I would ask Congressman Ehlers how close we are to a fusion reactor. Not very close. It seems to be receding about one year per year, so it is highly speculative, and it could take a heck of a lot of resources to try to do it.

There is no iron or steel on the Moon. Even if there were, to take the infrastructure to mine it and form it into something that would help us go to Mars is not there. You just boosted stuff out of the Earth's gravity well, you have dropped it into a 1/6 gravity well, and then you are going to boost it again. Why not just take it from the Earth in the first place, put it together in space, and go? So those are the kinds of debates I think we need to have. I am not saying I know the right answer, and I agree, we don't want to stop what we are doing, and I—believe me, I have been paralyzed by analysis. I have been working on all of these things since 1966, and we don't get there, and I want to see us get there by thinking of some fresh approaches and not just keep turning the crank the way we have been doing it for the last n years.

Chairman BOEHLERT. Dr. Fisk.

Dr. FISK. Just a couple of random comments here. You said a number of very appropriate things here. Let us take it as a given that we are going to extend the human presence into the solar system in time, then the question, as Norm Augustine says, it is simply a question of when do we start and who does it. I am one of those people who thinks we should start now and the United States should do it. Lead, at least. And I think that is a sentiment that, hopefully, is widely shared.

The question is—that you raised—of course a comment that you made is very much the appropriate one about presumably we are not going to stop. I mean, we are going to continue to do this. This is a—this is the journey we are planning to have here. My knowledge of the NASA plans is that they—the Moon is not a place that we are planning to stop or that we are planning to try and launch things from the Moon or use the resources to be able to get to Mars. It is premature to do that. But the plan is to try to use the Moon in an appropriate way to try to test out the capabilities on the route to Mars.

Now presume we don't stop there on the Moon. Suppose we find resources that we can use. Suppose our technology improves to where we can think about mining the Moon, maybe not in 10 years, 20 years, maybe in 50 years, maybe in 100 years, but presumably the event is to extend the human presence into the solar system and to use the resources, the capabilities that are available to us over that period of time, and as the—as appropriate or as the technology develops. I think that is a very appropriate plan. I think the main event to this thing is to begin to think on the time scales of not the decade—you know, not do we get to the Moon by 2020 but begin to recognize that this is the first step in the human expansion into the solar system, and it won't stop until we have done all of the appropriate things.

Chairman BOEHLERT. The gentleman's time has expired.

Mr. Smith.

REVIEW OF NASA CENTERS

Mr. SMITH. Regardless of the final decision in policy, whether we give a greater concentration for unmanned space flight for exploration or whether we don't, Senator Brownback has suggested that we review the ten NASA centers and have sort of a BRAC-type commission to review for greater, for lack of a better word, produc-

tivity and efficiency. Would you agree that a BRAC-type review is appropriate? We will start with you, Dr. Shirley, and then other comments, Dr. Young.

Dr. SHIRLEY. I think it is extremely appropriate, and I made, in my written remarks, the comparison with the Jet Propulsion Lab, not just because I worked there for 32 years, but because when people talk, JPL listens, because we are a contractor. We—JPL is a contractor. So we don't have the civil service, you know, workforce there in the background that you don't have to account really for where you put them. Every dollar of ours is scrutinized. Every dollar has to be agreed upon whereas when you are a civil service lab or a civil service center, you have a lot more flexibility to maybe be productive and maybe not be productive. There are an awful lot of good people at NASA. I am—there are terrific engineers and scientists at NASA, and I think they would be better served by looking at a potential for privatizing them in the sense that JPL is privatized. Or certainly, there may be redundant resources that should be looked at.

MANNED AND ROBOTIC SPACE EXPLORATION

Mr. SMITH. Any other comments on this issue? You know, there is—my experience is that any groups that use government funding are very wise to the political pressures on individual members that make those decisions. The Space Station, I think every state has some part of the Space Station, so groups from industry can come in from every state and meet, regardless of what the Members on this committee are, and say, "Well, boy, this is really important to our jobs and our state. It has been spread around."

I want to talk about manned versus unmanned flight and get your reaction a little bit, and that is if exploration is the overriding goal, then why not choose missions that maximize the potential for new discoveries for tax dollars, every tax dollar expended, and that, in my mind, is the unmanned space flight? And what we are doing on Mars right now is just so exciting. But to what extent can robotic spacecraft accomplish these exploration goals instead of humans at—certainly at less cost and certainly less risk to human life? And Dr. Young or Dr. Griffin or Dr. Fisk?

Dr. YOUNG. Well, I will start on that and refer back to something that Dr. Fisk discussed a bit earlier. It is no longer a question, in the minds of most of us in this community, of human versus nonhuman exploration. We are all excited about what the robots are doing on the surface of Mars at this moment. The question is how do you use robots in conjunction with human exploration. But as far as choosing the mission that can be done robotically, that is just looking for your keys under the streetlight.

The question is what are the important issues to find out about, and in the exploration of the solar system, clearly the origins of life is one of the foremost ones. In my opinion, the robotic missions are the appropriate precursor missions to tell you where to look and what to look for, but the examination is best done in situ by a trained biologist, scientist, astronaut.

Dr. FISK. I would agree with that. I mean, this is an evolution again. And I mean, if it is conducted that way, it is an evolution, you know, robotics leading to humans. I mean, humans currently

control the missions on the Martian surface. There is a 20-minute delay or whatever is the time. Oh, I am sorry. Is that better? Humans currently control the missions on Mars, but they live in Pasadena, and the missions are on the ground. It might be appropriate, you know, to do this in an evolutionary way with humans in Martian orbit for awhile and maybe not on the surface immediately and so on. But I mean, you have to think that through. But the idea is to accomplish the exploration, you are absolutely correct, but recognize that the human brain, the—you know, does introduce a capability that will be a long time before we can completely—we could duplicate with robotics. But their assisting each other is the ultimate goal to this thing.

You know, I think that is going to be the natural evolution of this thing, and that could well be—we have to be careful—the natural evolution of the science will be robotics to robotics with humans.

Mr. SMITH. I mean, with humans going out there regardless of what we are able to accomplish with the robotics and the——

Dr. FISK. I think we are going to——

Mr. SMITH.—nanotechnology?

Dr. FISK. I think we are going to send robotics out there, we are going to learn things, and we are going to continue to—and it will evolve to where the human and the robots are closer together than they are today.

Mr. SMITH. Thank you.

And Dr. Griffin, maybe react a little bit, and thank you from the University of Michigan. Just in terms of—it has been sort of my impression that man in outerspace and our space platform, the Space Station, was primarily to decide and learn how man can survive in outerspace as opposed to the exploration. So maybe sort of mend that into your response on this question.

Dr. GRIFFIN. Well, certainly for the last 30 years or more, because humans have not ventured beyond low-Earth orbit, any involvement with humans on a scientific basis has been as equipment operators, which is essential, or as test subjects, but they have not been exploring planets, because we haven't been going there. So I think we have got to get out of that.

I would say, overall—my own opinion is that—well, NASA's chief scientist, John Grunsfeld, recently, for public consumption, pointed out that the amount—the total amount of exploration on Mars to be accomplished by both MER A [Mars Exploration Rover] and MER B would be approximately equivalent to what one human geologist would do in one afternoon. And that is not a criticism of MER A or MER B on Mars; they are doing wonderful things, and they are doing things we cannot afford to do at present in any other way. But I think it is important to note that the 90-day missions, which are being forecast for those rovers, would be one day of activity for a human being. There is a lot of leverage in having a human even leaving aside the issues, which Len Fisk has pointed out, with which I strongly agree, that the human provides a certain adaptability and capability to be serendipitous that we don't get by other means.

Trying to decide today what the ultimate role of new worlds can assume in human civilization is like—is very much like saying in

1600 that we are going to go settle Jamestown in Virginia because we hear they can grow good tobacco. And it was true. It was not wrong, but it was so woefully incomplete as to be misleading. And yet it remains a fact that the initial settlement of Virginia was done because people wanted to get tobacco.

Chairman BOEHLERT. Thank you, gentlemen.

The gentleman's time has expired. Here is how we are going to——

Mr. SMITH. May I have—submit questions in writing to the panel?

Chairman BOEHLERT. By all means, and all Members will have the opportunity to submit questions in writing, which will be presented to the witnesses, and we would ask that you respond in a timely manner, if possible.

Here is how we are going to proceed as we move to conclusion. I have one further question, and then Dana Rohrabacher, the Chair of the Subcommittee on Space and Aeronautics will take over the Chair to recognize Ms. Jackson Lee. She will have a question. And then Mr. Akin, if he is here, will have a question, and that will wrap it up, because I know you have schedules you have to adhere to, too.

RETIRING THE SPACE SHUTTLE

Here is my question. A number of you have mentioned that retiring the Shuttle in 2010 seems unrealistic, yet the entire funding of the President's initiative depends on freeing up money now spent on the Shuttle. Do all of you agree that 2010 seems unrealistic? What date seems more reasonable? And what additional work on the Shuttle will need to be done if it is going to remain in service longer, keeping in mind what the Gehman Commission said there would be a necessity for recertification in 2010.

So one, is 2010 realistic? Two, what date, if you don't agree that that is realistic, would seem more reasonable? And what additional work do you foresee? Who wants to tackle that first? Dr. Griffin.

Dr. GRIFFIN. I will go. I think the date is approximately realistic. I wouldn't want to get wrapped around on the axle of whether it was 2010 or 2011. I would not want to see it go until 2013 or 2014. I think the way to view the situation is that the requirement should be posed to the managers and engineers charged with executing the remainder of the Station and Shuttle programs, and they should be held accountable to meet those goals. And if they can't, then we need to find new managers and engineers not in the program.

Chairman BOEHLERT. Dr. Shirley.

Dr. SHIRLEY. The only—my only concern is that it is—you can retire the Shuttle, but what are you going to do then? We have obligations for operating the Station, and we need to have a realistic scenario and a realistic set of alternatives if we are going to retire the Shuttle. Certainly there are risks with the Shuttle, but frankly, I was on a recent study, and there is just as much risk with the other approaches they are proposing. So I am not saying you shouldn't retire the Shuttle, I am just saying that if you do, you better have something else in mind or you are giving up the Station.

Chairman BOEHLERT. Dr. Young.

Dr. YOUNG. I don't know if 2010 is the right date or not, but I do know that it would be unfortunate if we went through another substantial period without having, from the United States, reliable access to space for humans. I don't think it is a very good idea for us to be in the position of depending entirely upon our international partners for access to the International Space Station or for other activities in space.

Chairman BOEHLERT. Dr. Fisk.

Dr. FISK. Very similar answers: set the goals, decide what you are doing. If the Space Station is to be completed, make sure the Shuttle is there to complete it. It will work backwards from what it is you want to do, put the Shuttle into the right—and make it an endgame as quickly as you can. The Shuttle has outlived its usefulness now. We need alternatives, and it is—but decide how to do it, you know, whether you are going to complete the Space Station, if you are going to resupply the Space Station, if you are going to use the Space Station, make sure you have the capability. Work backwards, put the Shuttle in its proper role, make it end as soon as you can.

Chairman BOEHLERT. You are all aware of the Gehman Commission and one of the many findings of the Gehman Commission was that arbitrary deadlines and the pressure to meet them, even when reasonable people would agree that they were unrealistic, made some problems within NASA. So—but if we don't meet the 2010 deadline with retiring the Shuttle, then the Gehman Commission has said, and NASA has embraced their recommendations, that it would require recertification to keep it going beyond 2010, which in and of itself is a very costly enterprise. So does any of that change any of your thinking?

Dr. GRIFFIN. Well, I think you can always adjust the goals of an engineering project as you move out in its execution, and you can decide whether the adjustment is reasonable and rational or is being caused by failure to execute properly. Those are decisions you can make as time goes on. But if you do not initially set a goal and a schedule, or as Len says, work backwards to them, what those goals and schedules imply, you will never get there.

Dr. SHIRLEY. I would just like to add one thing from science fiction from Robert Heinlein's "The Moon is the Earth's Mistress," Tom Stoffel. It means there ain't no such thing as a free lunch. Or free launch.

Chairman BOEHLERT. Or free launch.

Well, hearing some of the coverage of the aftermath of the *Columbia* tragedy, a number of times high-level officials in NASA were quoted as saying part of the problem was that Congress didn't meet NASA's budget expectations, and when Congress doesn't meet an agency's budget expectations, I would suggest it is very much in order to adjust those expectations and goals, because, as you say, there ain't no free lunch.

With that, let me turn the chair over to Chairman Rohrabacher and recognize in the process, Ms. Jackson Lee.

NATIONAL VISION FOR SPACE EXPLORATION

Ms. JACKSON LEE. Thank you very much, Mr. Chairman and to the Ranking Member for holding these important hearings. To the panel, let me apologize for my entry into the room. I was flying on aircraft that Chuck Yeager, obviously, in breaking the speed barrier, mine did not. And so, although I am a strong advocate of aviation and the space program, I thank you for your indulgence as I ask these questions.

Yesterday—first of all, let me say that the inspiration of this space program is spreading across the Nation. Yesterday, in Houston, I was with General Howell of NASA Johnson at a business luncheon where individuals were gathered to hear the vision and the mission and to, I guess, in essence, raise their hand in committal—commitment to helping us with this effort, both on the national level and certainly in educating our respective communities.

I think what I got out of that meeting is the importance of now renaming this vision to call it the Nation's mission for space or national space mission. I would welcome your comment on how we broaden this so that the stakeholders go beyond the beltway, because I believe that what Camelot did in that timeframe was to get everyone thinking they might be next in terms of being able to go forward.

So let me just offer a few comments and then just raise these questions, and forgive me if you have answered them, and I would appreciate it in the succinct way that you would. I think that the points made about Admiral Gehman's comments about arbitrary timelines are very crucial but also his comments about safety. And I don't believe you will get the American public to truly buy in until you convince them this thing called space and travel to space is safe and it is viable. So I would appreciate you highlighting the importance of wedding the safety of the Space Station as well as human space travel and your comment on the value of the Shuttle now, we realize that we look to the future, but the value of the Shuttle now.

The other thing is to note that this nation is becoming increasingly diverse. We don't see diversity much in our industry. We don't see diversity much in our very fine astronaut corps, whom I have the greatest respect for and we were doing a lot of embracing yesterday as a number of astronauts were at the luncheon. We spent a lot of time together. But we have got to begin to see in the industry and in this effort the faces of Hispanics and African Americans and Asians, and we certainly have done a fair job internationally with our international partners. But I welcome your thoughts on that.

And then my final point and let you all answer it is that Dr. Griffin says in his testimony that the entire Apollo program was about $130 billion in today's dollars. And so I would like to ask you what—to the panelists, was it worth it? What was the return on the investment, something we will have to make to the American public in terms of technology, education, inspiration of our youth, international leadership, economic stimulus, and you may have other factors? Did we dream? Did we grow? I know for a fact that we have done some things in health research. And would we expect

a similar return on $130 billion to go to Mars, as we discussed today, or the Moon, because I think the way we get to the next step on the journey is by making the entire Nation stakeholders, and I yield to Dr. Griffin, and would ask everyone if you were taking studious notes of my questions.

Dr. GRIFFIN. Wow. Give me 30 seconds. For my——

Ms. JACKSON LEE. In the——

Dr. GRIFFIN. From my part, Apollo was worth it. I tend to take a big picture view. I answer the question by analogy. If you look back at Renaissance Spain, what do you think of? You think of Queen Isabella, King Ferdinand, and Columbus' voyages. You don't think about battles between the Spanish and the Moors over who was going to control Spain and things that were actually very influential, but when you look back 500 years, you remember Columbus.

500 years from now, people will not be concerned about budget battles that we hold in Congress. They will remember that the United States caused the Apollo missions to happen. What have—we built an entire technology around that, the aerospace technology, which is the best in the world. Our entire defense establishment relies on it. We could have gotten it in other ways, I don't dispute that, but that is the way that we got it. We inspired at least a couple of generations of young people to obtain technical training, and they have used it in areas far outside aerospace. Norm Augustine was emphatic in pointing out the current discrepancy between U.S. engineers and scientists graduating and those in other countries. I strongly submit that the way to motivate scientific, technical, engineering training in the United States is not to have NASA adopt an education office, but to have NASA do the kinds of things that make young people want to get the education they need to get in order to participate.

MOTIVATION FOR SCIENCE AND MATH EDUCATION

Dr. SHIRLEY. I really appreciate your comments on diversity, having been there through the—when I was the only female engineer at JPL to where there are now 20 percent.

Ms. JACKSON LEE. And women are included, you are right.

Dr. SHIRLEY. So I think that it is very important for us to be able to engage people, especially young people. At the Science Fiction Museum, one of our prime objectives is to use science fiction to attract young people to be interested in science and engineering. And Dr. Young and I were just having a conversation about how many of our colleagues and our students say, "I got interested in this because I read science fiction." It is very important, though, not to do what Dr. Young said, for NASA to figure out how to sell what it wants to do better. What we need to do is to get everybody involved in formulating what NASA or what the Nation, I completely agree with calling it the national—or maybe even the international endeavor if we wanted to go that way. But it is not taking what NASA wants to do and selling it to people, which is what NASA always does. It is involving people in formulating what we are going to do and where we are going to go, and that is how they are going to get behind it.

RISKS OF HUMAN SPACE FLIGHT VERSUS OTHER ENDEAVORS

By the way, as far as safety, this is risky business. It is not going to be completely safe. People will pay $65,000 to be guided up Mount Everest with a high probability of dying, much higher than going up on the Shuttle. So safety, you have to be careful about trying to make things so safe that you can't afford them. And so I think we need to really put safety into perspective. When these astronauts go, they know they are taking a risk, and they choose to do it. And I don't think you should deprive people of that opportunity.

As far as return on investment, I think the lift of the human spirit that Apollo gave us was uncountable. I think the lift of the human spirit that Pathfinder did, my rover, I personally was involved with the little rover that went first, and so I feel like these are my grandchildren. They are on Mars now. But the number of web hits we get, the amount of excitement that is going on around even robotic missions, and if we make human missions really driven by what people think humans should be doing, I think we can generate that kind of excitement around human exploration.

Ms. JACKSON LEE. You—on the safety, you had mentioned to make it as safe as it can be.

Dr. SHIRLEY. As safe as we can afford.

Dr. GRIFFIN. 10 percent of people who have climbed Mount Everest have died.

Dr. SHIRLEY. And they paid to do it.

Ms. JACKSON LEE. Thank you, Dr. Shirley.

Dr. Young.

Dr. YOUNG. Let me try to respond briefly to each one of the questions. As far as the question of was Apollo worth it, I agree with Dr. Shirley and Dr. Griffin. Absolutely, it was the seminal event of the 20th Century. It pushed science, technology, and education in a way that nothing else has.

Diversity. I feel very much involved with, and very strongly about it as the director of the Massachusetts Space Grant Consortium. Space Grant, as you are probably aware, in each of the 50 states plus DC and Puerto Rico, has, as one of its principle goals, increasing the percentage of women and underrepresented minorities in the state's program. And it is achieving those goals. It could achieve them better, incidentally, if the funding for it went up to the request, but it is going in those directions through education in K through 12, education in college, and beyond. And we have to keep going. There is a long way to go, but it is effective.

On safety, this is risky business. Going into space is not easy, and I think that, as was said earlier, if we may—if we are too risk averse, we will never do anything. On the other hand, there is no justification for going into space merely to show the flying. We must go in—go there because there is a return in terms of science, in terms of technology, in terms of commercialization, that is that it is worthwhile. I, for one, believe that the Hubble Space Telescope must be serviced and that it is worth taking the risk in that case.

Dr. FISK. Being—sitting at the end of the panel, I get to say "Ditto," probably on these things, but let me just—so let me not re-

iterate the statements, many of which I agree with. Let me just comment a bit on the safety issue. I don't—we have this impression that the American public is very risk averse. You know, we simply will be intolerant if anyone is lost in space. I don't actually agree with that. I think the American public is justifiably intolerant of losing people in space if they don't understand the reason for which we are there. What—why was the risk taken? We should never send humans into space or—unless we can defend the reason that they were there and they were needed to be there and there was something exciting to do. And if we have done so, and despite the best that we could do, there is an accident, I think we are tolerant of that as a people. We have lost people before. And we lose people in many—we lose military people all of the time. And so I think this vision is very important to us, because it provides the rationale for why we are sending people forth into space. And if we buy the vision, then we have to buy the risks that go along with it, and we have to explain to people that there is a risk associated with it. But first the vision, then comes the acceptance of the risk. Without the vision, there is not the—no risk—no loss is ever tolerable.

Ms. JACKSON LEE. I thank the Chairman. I thank the Committee.

Mr. ROHRABACHER. [Presiding.] Thank you very much. Thank you.

Dr. Ehlers has a question.

COSTS OF HUMAN SPACE EXPLORATION COMPARED TO OTHER NATIONAL OBJECTIVES

Mr. EHLERS. Thank you, Mr. Chairman. I appreciate your courtesy of letting me go ahead of you, but I have just been notified I have votes in another Committee in a few minutes.

I first want to clarify a few things. In response to your question, Dr. Shirley, about fusion, my estimate is we will be ready in about 40 years, which is about the time I expect we would reach Mars without it. And 40 years is not a scientific estimate; it is a political estimate, given the way things work around here and the lack of a firm commitment, as Dr. Griffin said, about, you know, just saying—realize you are going to be in space and let us allocate a certain amount of money to it. I am just not optimistic about getting there much sooner, unless it costs much less than the Congress anticipates.

I would say, however, we do tend to treat NASA the way we treat the Navy. We have as many arguments about whether to build a new battleship or a new submarine as we do about whether or not to go to the Moon. And so the problem is the lack of long-term stability in funding and the lack of long-term planning on the part of both NASA and the Congress.

Let me add another comment before I leave. It seems to me that the keystone of the direction we are going to take is going to be what happens with the CEV, the Crew Exploratory Vehicle? I think Congress, without realizing it at this point, perhaps not even realizing it later, is going to look at that as the test of whether NASA can really produce something at a fairly quick rate at a fairly reasonable cost. And so NASA, I think, has a tremendous amount of work to do on the design. I have talked to them. They know rough-

ly what they want to do, but there are dozens of different options on how to do it. And they are going to have to narrow that down fairly quickly. They are going to have to come up with a concrete plan, get the money from us, and show that they can do it. And if they do, I think that there is a much higher probability of continuing with the rest of the plan. If that turns out to be another X–33 disaster, then we are talking very, very long time spans and very limited money in the future.

And I just wanted to get that on the record as well as one other comment. In the argument about robotics versus humans, clearly humans are more versatile, adaptable, analytical, and so forth, but the cost ratio, as I see it, is about 1,000 for one human. And I think we have got to do a fair amount of robotic exploration before we can intelligently send a human being out there to—so that we can optimize the use of the human being in deciding where the person should land, what they should—what equipment should go along, what they should be doing.

With that, I will yield back. Mr. Chairman, thank you for the time, and I have to go back.

Mr. ROHRABACHER. Just in time. Just in time.

Mr. EHLERS. Thank you.

SPACE SHUTTLE RISKS

Mr. ROHRABACHER. Would the panel like to comment at all on that or if we could just—all right.

I have a couple observations and then we will—and a couple questions. First of all, I forget who it was. You probably know. Was it Melville who believes the safest ship never leaves port? Was that—was it Melville who said that? I just—that quote sticks in my mind as we are discussing the risks that are involved in various space missions.

I would like to say, for the record, as well, today, when we are talking about the risks, that this focus on risk, and I think you have indicated, is a bit out of proportion, especially when you are talking to—compare it to people going up to Mount Everest, and then we realize that we are really involved with scientific missions and pushing the envelope in terms of human capabilities in America's space program, but that risk is certainly something well thought out and worth taking. I would challenge NASA to keep those admonitions in mind when trying to determine whether or not we are going to rescue the Hubble Telescope, because, from what I understand, NASA is planning to have one or two shakedown missions for the Shuttle that will essentially be aimed at proving whether or not the Shuttle is safer or not. But those missions will not be at the same time accomplishing something tangible, like saving the Hubble Telescope.

And so I would suggest that if NASA is going to test the Shuttle, it do so by conducting a legitimate mission and that is to put the gyro and the batteries in the Hubble Telescope, because that is one space project that we have paid for that, even though it got off to a very rough start, seems to have had such phenomenal success in providing us a benefit back for the costs that we have incurred. So that would be something that I would suggest tonight—or today that NASA take a serious look at and say the risk of another Shut-

tle mission, even—because we are going to do it anyway and then assigning them a job would be a cost-effective way of dealing with this—with the question at hand.

QUESTIONS ABOUT ICE ON THE MOON

A couple things about what has been said here today. Dr. Shirley, is there not hydrogen and oxygen on the Moon as well? And we know there is some amount of water. Wouldn't this be of some benefit to have a storage—a resource available to us on the Moon of hydrogen and oxygen?

Dr. SHIRLEY. Well, the water, maybe, is most likely ice in the permanently shadowed regions at the pole. And some of these lunar missions that Len Fisk mentioned, are going to go and see if it is really there. I mean Clementine took a look at lunar orbit——

Mr. ROHRABACHER. Right.

Dr. SHIRLEY.—took a look, but we are not sure it is there.

Mr. ROHRABACHER. Wouldn't that be of immense value if——

Dr. SHIRLEY. Possibly, except what it most likely is is a bunch of icy dirt, and we don't know how much there is, and getting at it and mining it is going to take lots and lots of equipment to be shipped from the Earth. Now all I am saying is you have to ship everything you use to get those resources from the gravity well of the Earth——

Mr. ROHRABACHER. Sure.

Dr. SHIRLEY.—and you need to look at the trade.

Mr. ROHRABACHER. Well, you quoted Tom Stoffel from "The Moon is the Earth's Mistress." And I seem to remember in "A Stranger in a Strange Land" that we were talking about water as being the most valuable resource. So you might keep that in mind.

Dr. SHIRLEY. Well, we know there is water on Mars.

Dr. GRIFFIN. Could I comment for just a moment?

Mr. ROHRABACHER. Certainly.

Dr. GRIFFIN. Even if we don't find water or find that it is not, early on, cost effective to mine it, let me point out that 7/8 of the mass of the liquid hydrogen and liquid oxygen propellant combination is due to liquid oxygen. 7/8 of the mass. If—and we know that parts of the lunar soil contain as much as 40 percent oxygen by weight, it is fairly easy to extract that oxygen simply by roasting the soil. The earliest lunar resource extraction that I predict we will perform will be to extract that oxygen, use it either on the Moon, or ship it elsewhere in lunar space, possibly into Earth orbit, there should be a way to make those trades among the more favorable ones that we can do. If we end up shipping hydrogen from Earth, instead of having to ship hydrogen plus oxygen, we will have saved 7/8 of the up-mass necessary to supply propellant for going to Mars or doing whatever. That is a nice place to start, and it is not an insignificant gain.

Chairman ROHRABACHER. I think that that is an excellent way to end this discussion today, however, just—maybe one more question, and that is, you know, we have got this—we have been talking about the way NASA works and the—we have heard NASA has got to do things differently to succeed. We have this X–Prize now that is really inspiring people to develop new types of suborbital

vehicles. Is there an X–Prize type concept that we might use to encourage people to develop things that would help us in this next stage of——

Dr. GRIFFIN. No fair. That was one of my questions to you.

Chairman ROHRABACHER. So that—but what should they be?

Dr. SHIRLEY. Well, I think that NASA's idea of the "Challenge" prizes, which is in their plan is not a bad idea. The only thing I am worried about is that we can challenge people all we want, but will NASA actually use the results. And what I am worried about is that there is an awful lot of technology out there that NASA pays for and they never use because it is not part of the existing infrastructure and the way things are done. So yes, those prizes would be a good idea, but there needs to be an additional component in where is the gate in which you start—you know, how do you infuse those into this block that they are talking about——

Chairman ROHRABACHER. Okay.

Dr. SHIRLEY. Into this spiral development. How does that work?

Chairman ROHRABACHER. Okay. And one last thought on the elevator. I think the elevator is worth looking into. If we are going to spend billions of dollars in recreating the Saturn V rocket, I mean, something that we did back in 1960, I mean, let us start using our imagination to build something we haven't built before and could do—could possibly work. But then again, if it doesn't work, boy, that would be the biggest boondoggle in the history of all humankind.

So those are the decisions we have got to look to and we have got to talk about seriously. I want to thank each and every one of the panelists for coming today and making your contribution to the really important discussion that will lead to the decision-making that will lead us to the next step in human exploration of space.

So thank you all very much. We are adjourned.

[Whereupon, at 12:46 p.m., the Committee was adjourned.]

Appendix:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Norman R. Augustine, Former Chief Executive Officer, Lockheed Martin; Chair, Advisory Committee on the Future of the U.S. Space Program

Questions submitted by Chairman Sherwood Boehlert

Q1. To the best of your knowledge, are there alternative "end states" to assembly of the Space Station other than that which NASA currently plans that would meet all or most of our international commitments, would require less expenditures of funding, and would still allow the necessary science to be conducted on the effects of space on human physiology?

A1. I am personally unaware of any particular "end states" in the Space Station program other than that which is currently planned. This is, however, an important question worthy of exploration by those in a position to conduct a more knowledgeable evaluation.

Q2. At the hearing, Dr. Fisk recommended that NASA proceed step by step with the exploration initiative to "learn as you go." What do you believe are the significant steps that NASA must take as it implements the initiative, and what kind of milestones or gates do you believe, if any, Congress should set to ensure that the initiative is proceeding well and NASA is properly learning as it is going?

A2. "Learning" for the space exploration initiative can be grouped into three basic categories. The first of these has to do with the engineering steps required, to accomplish the mission, including identifying an appropriate mission architecture, developing advanced propulsion systems and creating manufacturing capabilities (for example the production of propellants) at locations other than the Earth's surface. Second, additional learning is needed of the long-term effects of space exposure on humans, particularly in the trans-Earth-Mars environment. Third, a great deal of knowledge remains to be obtained concerning the nature of Mars, its history and the implications thereof for those of us here on Earth.

I believe that any "gates" that the Congress elects to impose should be focused on the first two of the above-mentioned areas of endeavor. As the mission is further defined, critical milestones should become more apparent. It is probably premature to establish specific gates at this point and time—although highly appropriate once the project is definitized.

Q3. What recommendations, if any, would you make on how best to organize NASA to undertake the President's space exploration initiative?

A3. I would recommend that a strong project office led by an experienced project manager be established reporting directly to NASA headquarters with full authority over all contractor and NASA center activities relating to the undertaking.

Q4. We are now totally dependent on the Russians to provide crew rescue with their Soyuz vehicles. However, Russia fulfills its Soyuz obligations to the international partners in April 2006. After that time, it is not clear how NASA plans to provide a crew rescue capability for astronauts on-board the Space Station.

- *Do you believe NASA should develop its own crew rescue capsule for the Space Station? How soon do you think a crew rescue capsule could be developed?*
- *Do you believe that the Crew Exploration Vehicle should be designed to service the Space Station as well as carry out missions beyond low-Earth orbit?*

A4. The Commission on the U.S. Space Program, which I chaired about a decade ago, recommended that NASA develop a crew rescue vehicle for the Space Station as well as for other possible future missions. While I do not have the basis to make an estimate as to how long it would take to conduct such a development today, it continues to be, in my opinion, an appropriate undertaking—assuming that the U.S. remains committed to operating the Space Station. The reviews conducted by our Commission on the Future of the U.S. Space Program, based upon then available projections of technology, indicated that a crew exploration vehicle could be designed to serve a Space Station as well as support missions beyond low-Earth orbit. This is an issue which is quite amenable to engineering analysis and should not require a great deal of subjective decision-making.

Questions submitted by Representative Bart Gordon

Q1. What, if any, are your biggest concerns with respect to the President's space exploration initiative? What should Congress be focusing its attention on as we evaluate the initiative?

A1. In my opinion, the President's initiative is a sensible and appropriate one. My principal concern would be that an undertaking of this magnitude, inevitably involving non-trivial risk, should be undertaken only with fully adequate funds.

This is necessary to provide financial reserves, backup technical approaches and to conduct the necessary tests and analyses to reduce risk to an acceptable level.

Q2. It has been argued that one of the main rationales for human space exploration is its inspirational value. However, the Mars Pathfinder and the Spirit and Opportunity Mars Rovers have demonstrated that robotic missions are capable of capturing the public imagination.

- *Given that, what do you think are the most compelling justifications for human exploration?*
- *When should human exploration missions be contemplated—that is, should they be deferred until as much as possible has been accomplished robotically, or should human missions be an early goal? Why?*

A2. Robotic missions do capture the public imagination, yet, in my judgment, there is a very great difference between placing humans on Mars as compared to exploring Mars with robots. One need only consider the difference in reaction to the early Soviet robotic lunar missions and the mission of Neil Armstrong and Buzz Aldrin. The Commission on the Future of the U.S. Space Program contrasted the likely public impact of a hypothetical rocket launch to place instruments on the summit of Mt. Everest as compared with Sir Edmund Hillary and Tenzing Norgay's inspiring climb to the summit. Nonetheless, there are important roles for both robotic and human exploration. Robotic exploration is at its best in gathering large quantities of data and performing relatively routine tasks at very remote or hazardous locations. Humans are at their best when undertaking tasks requiring great flexibility and real-time decision-making.

With regard to timing, there should undoubtedly be overlapping missions of robots and humans, with robotic activity beginning at an earlier time not only because of its earlier feasibility but also because of its role in reducing the risk of human missions.

Q3. What do you consider an appropriate role for the private sector to be in the exploration of the solar system?

A3. I believe strongly in the power of the free enterprise system and therefore conclude that the private sector should have primary responsibility for carrying out missions to explore the solar system. At the same time, I believe that the government bears an important responsibility and capability for the oversight and direction of the work to be undertaken in the private sector.

Q4. One of the key questions we will have to wrestle with as we evaluate the President's proposed initiative is whether NASA has the capabilities needed to carry it out successfully. Experienced NASA personnel will be retiring just as the initiative is getting going. New employees will not have any significant experience in human space flight and will need time to acquire it. At the management levels of NASA, many of the key human space flight and exploration positions currently are held by retired generals and Admirals with no previous space-related experience.

- *How confident are you that NASA will have the experience and skills based needed to conduct the initiative safely and successfully?*
- *If you aren't, what would you recommend be done?*

A4. During the Apollo Program NASA and the Department of Defense were generally considered to represent the leading edge of technology—and therefore were able to attract many of the Nation's "best and brightest" in the fields of science and engineering. Today, many of those individuals are instead attracted to such fields as bioengineering, nanotechnology and informatics. For NASA to draw the needed capabilities for a human Mars mission will require a clear and unambiguous long-term commitment to the exploration of space, particularly providing reasonable certainty that the needed funds will be available.

I might note that I recently came across a photograph of the control room during the Apollo missions and my immediate reaction was, "They look like a bunch of

kids!" Indeed, those of us involved in the early days of the space program were "a bunch of kids." This is not to say that experience is unimportant; it is obviously very important. At the same time, the energy and creativity of young people and the focus of their educational experience on the very latest technological advancements is not to be under-estimated.

Q5. Your 1990 committee recommended that the space science program be given the highest priority for funding, and that science activity should be the "fulcrum of the entire civil space effort."

- *Did your committee ever debate whether exploration should be the main focus of the civil space program?*
- *If so, why did you reject that in favor of a science-based focus?*

A5. The Committee on the Future of the U.S. Space Program identified a number of possible objectives for America's space program. We concluded that a "balanced" program would be the most appropriate program for America to pursue, and that such a balanced program should include unmanned missions, manned missions, science, and exploration activities. Nonetheless, we did indicate that within a "balanced program" science should be given a degree of preeminence. Although there were many reasons for this conclusion, foremost was the fact that new knowledge is principally the product of *science,* and that new knowledge underpins much of the progress one can anticipate in fields ranging from engineering to the health of the Nation's economy.

Q6. Your 1990 report argued for a "go as you pay" approach to a human mission to Mars, indicating that there is no particular urgency in accomplishing such a mission. Would canceling or deferring existing and planned Earth and space science activities, as well as R&D on advanced aeronautical and space transportation systems in order to shift money to the President's exploration initiative be consistent with your committee's conception of a "go as you pay" approach?

A6. Clearly, any program of human exploration of Mars must compete against alternative undertakings in the budget process. Nonetheless, our committee's conception of a "go as you pay" philosophy would be consistent with the notion that other priority missions should not be disrupted to make possible an early human mission to Mars. Equally important, it was our intent that any Mars mission should be fully funded, including the provision of appropriate reserves to deal with contingencies. Any Mars mission will inevitably represent a major engineering undertaking, one which should be pursued in as efficient a manner as possible, but in no case should "corners be cut"—given the importance of the mission to our nation's image and the implications for risk of the astronauts involved in the project.

Questions submitted by Representative Nick Lampson

Q1. At our committee hearing last February 12, we asked the Director of the Office of Science and Technology Policy and the Administrator of NASA if the President had asked the cost of the Moon/Mars initiative, and, if so, what was he told. Their responses did not provide much clarification.

- *How much uncertainty in cost estimating should Congress be willing to tolerate in large scale, long-term programs like the President's initiative?*
- *Would you, as a corporation chief executive officer and as a board member, be willing to commit to long-term, high-risk programs if you were told that the anticipated length of time for the program made it impossible to provide accurate cost estimates? If so, why?*
- *If the cost estimates are likely to be uncertain, what measures should Congress use to assess the agency's performance in implementing its initiative?*

A1. This is an important and provocative question. First and foremost, the necessary "proof of principle" developmental work should be undertaken to reduce the uncertainties in cost estimating as much as possible. On the other hand, in any enormous technological undertaking, including a human mission to Mars, uncertainties will always remain and some cost risks will simply need to be managed because they can never be entirely limited. Given this circumstance, one needs to rely to a considerable degree upon statistical estimations of cost. This is not a particularly satisfactory situation since we will have only one Mars program and thus statistical averages are not particularly meaningful. Nonetheless, it should be possible to assign reasonable probabilities to various cost outcomes such that one could estimate,

say, an 80 percent confident cost; a 50 percent confident cost and a 20 percent confident cost.

With regard to the perspective of a board member or chief executive addressing long-term, high-risk programs, virtually all corporate *research* has in it highly inaccurate cost estimates and schedules. As an undertaking moves towards engineering development, however, it would be expected that considerable refinement of those estimates should be possible. While most corporate directors would be reluctant to commit to programs that could threaten the existence of a firm (i.e., where cost uncertainties are sufficiently great to make this outcome a meaningful possibility), it would not be uncommon to make commitments for programs with enormously high payoffs yet harboring significant but "survivable" downsides. One of the problems with corporate America today is its focus on near-term, high confidence outcomes at the expense of longer-term, higher-risk (but higher payoff) pursuits.

In managing major projects with uncertainties in cost and schedule, three lessons stand out. The first of these is that a series of major programmatic gates should be established and modified as knowledge is gained. The program should be reassessed at each of those gates. Second, reserves in terms of schedule, funds and technical approaches should be established commensurate with the uncertainties being confronted. Third, specific risks should be identified and plans created to manage those risks.

Q2. Although Congress has not yet come to any decisions on the President's proposed space initiative, NASA is proceeding to cancel already planned hypersonics R&D projects as well as advanced rocket engine R&D in order to free up money for the initiative. That would appear to run counter to the recommendation of your 1990 Committee that NASA needs to continue to invest in its technology base and not let funding be diverted.

- *How concerned should we be, and what would you recommend be done?*

A2. While I believe that a human mission to Mars is the next logical step in the human space program and one well-worth undertaking, I believe it would have been the view of our committee that such a program should not be undertaken at the expense of other important scientific and technological accomplishments.

There can be no question that one-day visitors from some nation will land on Mars. It is my earnest hope that they will be from the United States. Nonetheless, our committee recommended that the first step in a mission to Mars is to carefully define the mission architecture and to put in place the technological building blocks which reduce risk to an acceptable level. Only when that has been accomplished would it be appropriate to begin large-scale engineering activities associated with the conduct of the mission itself.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Michael D. Griffin, President, In-Q-Tel; Former Chief Engineer, NASA; Former Associate Administrator, Exploration Systems, NASA

Questions submitted by Chairman Sherwood Boehlert

Q1. To the best of your knowledge, are there alternative "end states" to assembly of the Space Station other than that which NASA currently plans that would meet all or most of our international commitments, would require less expenditures of funding, and would still allow the necessary science to be conducted on the effects of space on human physiology?

A1. Given the constraints we are assuming—meeting the international commitments and allowing the study of human physiology—I don't believe there are any alternative "end states" for the ISS, certainly none that allow us to save any money. Indeed, it can be argued, and I have argued, that we need to restore Habitation Module funding if we are indeed serious about our ISS commitments.

That said, I believe the greatest opportunity to save money during the remainder of the ISS program might lie, not in what "end state" we reach, but how we go about getting there. NASA's own budget estimates, codified in its February "sand chart," indicate that some $28B is planned to be expended on Shuttle operations between now and 2011. I would submit that an earlier cessation to Shuttle operations, possibly at "U.S. Core Complete" or even before, would allow us to use presently programmed Shuttle operations money for the development of a shuttle-derived heavy lift launch vehicle. Once that vehicle is available, the remaining ISS modules could be deployed in clusters, using fewer launches, quite likely saving substantial money overall. I believe this issue should be examined more carefully than it has been to date.

Q2. At the hearing, Dr. Fisk recommended that NASA proceed step by step with the exploration initiative to "learn as you go." What do you believe are the significant steps that NASA must take as it implements the initiative, and what kind of milestones or gates do you believe, if any, Congress should set to ensure that the initiative is proceeding well and NASA is properly learning as it is going?

A2. I think that Dr. Fisk's comment is on point; indeed, NASA will have no choice but to "learn as we go." Doing so is a fact of life, and we should structure the exploration program to accommodate that reality.

Nothing in NASA's current infrastructure or flight programs is oriented toward return to the Moon or missions to the near-Earth asteroids or Mars. A long period of infrastructure development will be necessary to recreate, and go beyond, the capabilities the Nation possessed at the time of Apollo. Among the steps necessary to take are:

(a) Operational Earth-orbital CEV NLT 2009, significantly sooner than currently planned.
(b) ISS Habitation Module, extendable to lunar/Mars surface use, by 2010.
(c) Heavy-lift launch vehicle NLT 2011.
(d) Lunar lander system augmentation of CEV by 2012.
(e) Development of lunar surface-suit technology ready for operational deployment by 2013.
(f) First manned lunar return by 2014.
(g) Lunar surface nuclear power reactor available by 2015.
(h) Robotic demonstration of *in-situ* resource utilization on Mars by 2016.
(i) Ground tests of nuclear thermal space propulsion engine by 2017.
(j) Mission to Phobos/Deimos by 2018.
(k) Robotic demonstration of Mars entry/descent/lander systems by 2019.
(l) Manned landing on Mars by 2020.

NASA should be required to offer a plan to meet these goals, or a similar set of such goals, by approximately the dates indicated. The periods of time specified for the accomplishment of the stated goals are consistent with past practice in the U.S. civil space program; NASA should be held to such performance in the future. The plan will be developed in stages, and should take into account the necessity to learn from ongoing operations. Congress should be easily able to judge whether the plan is being met, or not, and take action accordingly.

Q3. What recommendations, if any, would you make on how best to organize NASA to undertake the President's space exploration initiative?

A3. My own opinion is that NASA's organization is not, per se, the problem. There are minor issues; for example, at present there exists unnecessary and harmful competition between Codes M, T, S, and U, with no overriding authority short of the Deputy Administrator—who cannot be expected in intervene in day-to-day programmatic issues—to make decisions as appropriate to further the initiative. But this and similar matters are easily remedied. More broadly significant is the fact that NASA needs a clear statement of purpose from the Congress, supporting the President's direction on the exploration initiative. If Congress does not concur with, and support financially, the stated vision, it cannot be attained. Congress must verify that competent people are selected to manage NASA to achieve the stated vision; aggressive goals should be set, and accountability for their achievement must be demanded.

Q4. We are now totally dependent on the Russians to provide crew rescue with their Soyuz vehicles. However, Russia fulfills its Soyuz obligations to the international partners in April 2006. After that time, it is not clear how NASA plans to provide a crew rescue capability for astronauts on-board the Space Station.

Q4a. Do you believe NASA should develop its own crew rescue capsule for the Space Station? How soon do you think a crew rescue capsule could be developed?

A4a. The ISS CRV should be a derivative of the planned Earth-orbital version of the CEV; there is no need to have two separate designs. Done expeditiously, the first versions of this vehicle should be available by 2009. In the meantime, NASA should be exempted from the Iran Non-Proliferation Act, and should purchase additional Soyuz vehicles from Russia to serve the CRV function.

Q4b. Do you believe that the Crew Exploration Vehicle should be designed to service the Space Station as well as carry out missions beyond low-Earth orbit?

A4b. From the answer above, "yes."

Questions submitted by Representative Bart Gordon

Q1. What, if any, are your biggest concerns with respect to the President's space exploration initiative? What should Congress be focusing its attention on as we evaluate the initiative?

A1. I will begin by noting, as I did in testimony, that I believe the vision for the space exploration initiative enunciated on 14 January by President Bush is essentially the right vision. Further, I believe this view is held by most people in the space policy community. Indeed, the geography of the solar system leaves us little flexibility in the matter; the Moon, Mars, and Near-Earth Asteroids are the logical destinations. Each is interesting in its own right, and collectively they constitute the places we can envision reaching over the course of the next couple of generations. So I have no concerns about the vision itself.

I am concerned about the perception that the vision constitutes, or should constitute, a wholly new burden upon NASA and the federal budget. I do not believe this is so, or should be so. While some amount of "new money" would be highly desirable, it should be small. The essential argument to be held concerns what NASA and the Nation should be doing with the money already allocated to manned space flight. The argument should not be about how much new money is required, or how much money should be redirected from other NASA enterprises into manned space flight. When and as we see the results obtained from implementing this new vision, we can reconsider how much of our nation's treasury should be allocated to it.

Congress should focus on the broad thrust and timeliness of the goals NASA enunciates and works toward. Architectural details are not as relevant as broad measures of merit. It is worth noting that, during Apollo, 18 months passed between the decision by President Kennedy and the Congress of that time to initiate the program, and the final decision to adopt lunar orbit rendezvous as the architecture by which the mission would be accomplished. Yet, the goal was achieved in eight years and two months following Kennedy's historic announcement. The entire Gemini program—ten manned flights in twenty months—was implemented in four years from announcement to completion. These are the kinds of things to which Congress should be attending. When NASA announces—years in advance—that the first manned flight of CEV will take place in 2014, ten years from the present, it should raise the reddest of red flags. A program paced according to such a schedule is inherently unwieldy and unworkable, and the Congress should require better.

Q2. It has been argued that one of the main rationales for human space exploration is its inspirational value. However, the Mars Pathfinder and the Spirit *and* Opportunity *Mars Rovers have demonstrated that robotic missions are capable of capturing the public imagination.*

Q2a. Given that, what do you think are the most compelling justifications for human exploration?

A2a. Humans are intensely interested in exploration, as shown repeatedly by the interest in robotic explorers such as *Pathfinder, Spirit,* and *Opportunity,* and for that matter the Hubble Space Telescope. The best rationale for human exploration is exactly the same as for robotic exploration—to learn and know new things, to know new places, to make those places part of the human scope and experience. While there are places only robots can go, it remains true that, as Mr. Augustine has put it, there is a difference between placing an instrumented package at the top of Mt. Everest, and its conquest by Hillary and Tenzing. When magnified to encompass whole new worlds that difference, difficult to quantify but impossible to ignore, is precisely the difference between robotic and human planetary exploration. I believe that difference is worth the money and the risk to human life with which it is purchased.

Q2b. When should human exploration missions be contemplated—that is, should they be deferred until as much as possible has been accomplished robotically, or should human missions be an early goal? Why?

A2b. Historically, when it was possible to do so, space exploration by humans has been preceded by a measured program of robotic exploration, as much to determine the characteristics of the environment as for any scientific purpose. And it is worth noting that robotic exploration has continued even after the cessation of the Apollo voyages, over three decades ago. So, while the two endeavors are usefully coupled, it is not appropriate to defer human exploration until "as much as possible has been accomplished robotically." That goal is not reachable; there is no end to useful robotic exploration. Human exploration should being when robotic exploration has revealed enough of the environment to allow us to know where we want to go, and why, and what hazards are likely to be encountered.

Q3. What do you consider an appropriate role for the private sector to be in the exploration of the solar system?

A3. My quick answer on this point is "as much as possible, as soon as possible." To the extent that the U.S. Government—through NASA—can express requirements to be satisfied and a price to be paid for meeting them, we will be better off. NASA's proper role is to design the mission architectures to be implemented. The more that we can adopt best commercial aerospace practices and procedures during such implementation, as opposed to adopting a classic captive government contractor model, the better off we will be.

Q4. One of the key questions we will have to wrestle with as we evaluate the President's proposed initiative is whether NASA has the capabilities needed to carry it out successfully. Experienced NASA personnel will be retiring just as the initiative is getting going. New employees will not have any significant experience in human space flight and will need time to acquire it. At the management levels of NASA, many of the key human space flight and exploration positions currently are held by retired generals and Admirals with no previous space-related experience.

Q4a. How confident are you that NASA will have the experience and skills based needed to conduct the initiative safely and successfully?

A4a. I am not confident that the NASA management team today has the experience and skill necessary to implement the vision, for precisely the reasons implied by the question—many of the individuals in question simply have not acquired their career experience in the space business. Military systems acquisition, to use a phrase coined by a friend at NASA, is simply not the same as building the *Nina,* the *Pinta,* and the *Santa Maria,* if the analogy is not overdrawn.

Space systems engineering and development is not an endeavor wherein one can do one's on-the-job-training by starting at the top. It should not be necessary to insist that NASA bring on-board, as top-level management, people with top-level space flight engineering and management experience. But apparently it is, and Congress should so insist.

Q4b. If you aren't, what would you recommend be done?

A4b. Today's NASA is as it is because it was assembled to serve the needs of what is, frankly, a rather mundane program, the flying of the Space Shuttle and the assembly of the International Space Station. More than one observer has characterized it as a space "jobs program" and, while somewhat unfair, this characterization is not entirely inappropriate. NASA has retained, at the working level, a very large share of the best people in the aerospace industry, simply because of their passion for the Agency's mission. But while this is so, it remains true that, by and large, the best people do not flock to routine or mundane programs. This is especially true when salaries, by industry standards, are very low and when, as now, we seem more concerned about government-industry "revolving door" issues than with doing what is necessary to make it simple and easy for government to attract and retain the best talent.

If we can address the above concerns, and if the new exploration initiative is approved, endorsed, and funded by Congress at reasonable levels and with apparent bipartisan consensus, it will not be difficult to attract the best people from industry, government, and the laboratories to manage it. This was the experience of the Strategic Defense Initiative Organization, Apollo, the ICBM program, and the Manhatten Project. The best people are drawn to the most challenging programs. So it will be again.

Questions submitted by Representative Nick Lampson

Q1. Until several years ago, development of a new reusable launch vehicle that could significantly reduce the cost and increase the reliability of access to space was a major national goal. However the budget plan accompanying the President's new space initiative envisions no additional funding for such R&D through at least 2020. Do you believe that is an appropriate decision? If so, why? And if not, why not? What would you recommend be done?

A1. I think it is wholly inappropriate for the Nation—through NASA—*not* to be funding such a development. While I have consistently championed the re-development of a heavy-lift launch vehicle to enable return to the Moon, and expeditions to Mars, it remains true that most of our nation's day-to-day spacelift requirements will be in the smaller size range, say 10 metric tons as a round number, with no intent to be overly precise with this estimate. Space launch costs will remain unacceptably high until we take on the problem of developing operational, substantially reusable, launch vehicles for this payload class. This remains an R&D problem, and the government agency in whose bailiwick it logically falls is NASA. Development of such technology should be viewed as a requirement, an obligation, of the Nation's space agency, wholly apart from its mission to explore. It must be demanded, and funded, by the Congress, and the Agency's managers should be held to account for its completion. This is the single highest-priority space technology development need confronting the United States.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Donna L. Shirley, Director, Science Fiction Museum; Former Manager, Jet Propulsion Laboratory's Mars Program; Former Assistant Dean, University of Oklahoma Aerospace Mechanical Engineering Department

Questions submitted by Chairman Sherwood Boehlert

Q1. To the best of your knowledge, are there alternative "end states" to assembly of the Space Station other than that which NASA currently plans that would meet all or most of our international commitments, would require less expenditures of funding, and would still allow the necessary science to be conducted on the effects of space on human physiology?

A1. Unfortunately, I am not familiar enough with the current design of the Station to answer specifically whether the development could be truncated to save money without breaking our international commitments. Certainly I would think that restricting experiments to those on physiology would help, but the international elements of the Station are not all focused on these issues. In addition, many of the elements of the Station that remain to be flown have already been built at considerable expense and it isn't clear how much would be saved by not flying them.

As Dr. Young pointed out in his testimony, physical preparation for a long zero-g or even partial-g trip requires that a centrifuge be included in the Station and I don't know the status of construction of this facility.

On the economic principle that "sunk cost" should not be included when making an economic decision NASA or an independent entity (e.g., the GAO) should be charged with looking at the cheapest way to achieve the goals of satisfying our international commitments while getting the physiological information necessary to design human exploration missions. This may or may not include completing the Station as planned.

Of course all of these issues are dependent on the choices made about access to space. The picture will be very different with and without the Shuttle.

Q2. At the hearing, Dr. Fisk recommended that NASA proceed step by step with the exploration initiative to "learn as you go." What do you believe are the significant steps that NASA must take as it implements the initiative, and what kind of milestones or gates do you believe, if any, Congress should set to ensure that the initiative is proceeding well and NASA is properly learning as it is going?

A2. NASA has procedures in place in its management instructions, (e.g., NMI 7120.5A. "NASA Program and Project Management Processes and Requirements"), which require independent reviews of programs before they are allowed to obligate money. These reviews have not always been held for large, politically sensitive projects like Station. NASA should develop a specific plan and program to complete the Station, focusing on international commitments and physiology, and have these plans reviewed by independent entities per its own policies.

The plans should indeed be "learn as you go," and should be decision-tree based. For instance, what must be known about Shuttle reliability to return it to flight? What are other ways of supplying the Station and what should be done to exercise these options? NASA should be capable of answering these questions. Unfortunately, I am not sanguine that NASA has the internal capability to make these trades, particularly in the politically intense climate in which it must operate. I would suggest that reviews be held, per the NMI 7120.5A, at the various budgetary phases, and that the GAO or OMB be included in these regular in order to give Congress insight.

Specific steps would be, in the next six months:

- Develop a return-to-flight plan for the Shuttle.
- Develop the minimum list of mission requirements for Station support to human exploration.
- Compare this list with already-built elements of the Station and select only those elements that are needed to meet the requirements.
- Do the same for international elements.
- Develop a set of alternatives to the Shuttle, including the use of private and international launch capability, and develop a set of metrics for selecting between the alternatives, including costs.

Then, in the six months after that, select the alternatives to pursue, and revise the current Station plans to head in this direction. Review progress at least on an

annual basis and ensure that the metrics are actually measured and are used to make decisions about how to proceed.

Q3. What recommendations, if any, would you make on how best to organize NASA to undertake the President's space exploration initiative?

A3. I strongly recommend that a BRAC-like process be applied to NASA. It is not clear that all of the human space flight centers are needed to efficiently operate a human exploration program. Next, I believe that NASA would be much more effectively operated if its centers were converted to contractor-operated facilities, such as JPL is now.

Finally, I believe that NASA needs competition, at least in the area of launch capability. While none of the current private launch companies can replace the Shuttle, they could conduct resupply operations within a few years which would require the Shuttle only to launch the very large payloads. There is no reason that if the private launch companies can launch tourists with an acceptable level of risk they should not also be able to launch crews to the Station.

Questions submitted by Representative Bart Gordon

Q1. What, if any, are your biggest concerns with respect to the President's space exploration initiative? What should Congress be focusing its attention on as we evaluate the initiative?

A1. My biggest concern, as I mentioned in my Testimony, is that the Moon initiative is a diversion from the real exploration of Mars, and that good, rigorous analysis is needed to really evaluate whether, for instance, the use of lunar resources (e.g., oxygen) is worth the cost of obtaining them. There are many advocates for a lunar initiative who seem to be basing their advocacy on this resource issue. This is a fertile area for analysis, but should be done independently of those advocates. In Apollo, Marshall and Johnson were advocating different approaches to reaching the Moon. One center insisted that rendezvous of elements in Earth orbit was best; the other wanted to have the rendezvous in lunar orbit. The spacecraft manager, Joe Shea, required each of the centers to analyze and advocate the point of view that they didn't hold. This revealed a lot of excellent issues and the decision to use lunar rendezvous was the outcome. NASA might take this approach to Moon vs. Mars.

My second concern is that the initiative is so under-funded as to be infeasible. Even with non-human exploration projects being slain all over NASA, the projected near-term budgets for specific elements such as the Crew Exploration Vehicle seem to be very low. While there appears to be ample funding over the long-term, at least in terms of the total dollars planned, without a specific action plan it is very difficult to assess whether this is indeed the case. Congress should put a budget cap on this activity, insist that specific plans and designs be developed and costed, per NASA NMI's, and insist on very hard-nosed reviews of these plans and designs.

My third concern is that all non-exploration science should not be sacrificed for the exploration program. Canceling or curtailing the Sun-Earth Connection, for example, will leave a gaping hole in data needed to assess the safety of human missions beyond LEO.

Q2. It has been argued that one of the main rationales for human space exploration is its inspirational value. However, the Mars Pathfinder and the Spirit *and* Opportunity *Mars Rovers have demonstrated that robotic missions are capable of capturing the public imagination.*

- *Given that, what do you think are the most compelling justifications for human exploration?*
- *When should human exploration missions be contemplated—that is, should they be deferred until as much as possible has been accomplished robotically, or should human missions be an early goal? Why?*

A2. As a person intimately involved in the rover missions, I can attest to the fascination that these missions had for the public. The most compelling justification for humans is, as I stated in my testimony, that humans need to explore—including taking risks to "be there" personally. Humans are unlikely to ever be as cost-effective as robots for carrying out science.

However, if we defer humans until robots have "completed" their exploration tasks, we will never send humans. Even exploring a relative small planet like Mars will take many, many years. We need to robotically collect enough data about Mars (or the Moon) to reduce the risk that humans will not survive the trip, or that they

will not be useful when they get there. Then we need to get on with figuring out how best to let humans do what they need to do—to explore. And this exploration with humans will necessitate that robots go along as precursors to set up infrastructure, as associates in exploration, and as extenders of human senses and capabilities.

Q3. What do you consider an appropriate role for the private sector to be in the exploration of the solar system?

A3. I think the government should provide incentives to the fledgling private launch industry, much as it incentivized the early aviation industry. There is currently little competition to drive down launch costs. Consideration should be given, not just to "prizes" of a few tens of millions of dollars, but to allowing private industry to bid on carrying out elements of the human exploration program.

NASA should have a much more open decision process about selecting objectives and architectures for human exploration, which would allow the private sector to propose how they would accomplish these objectives.

Q4. One of the key questions we will have to wrestle with as we evaluate the President's proposed initiative is whether NASA has the capabilities needed to carry it out successfully. Experienced NASA personnel will be retiring just as the initiative is getting going. New employees will not have any significant experience in human space flight and will need time to acquire it. At the management levels of NASA, many of the key human space flight and exploration positions currently are held by retired generals and Admirals with no previous space-related experience.

- *How confident are you that NASA will have the experience and skills based needed to conduct the initiative safely and successfully?*
- *If you aren't, what would you recommend be done?*

A4. I am not at all confident that NASA will have the capabilities to implement this program, and I recommend that a BRAC-type process be implemented to look at closing and/or repurposing some centers. In addition, I recommend converting civil service centers to contractor-operated entities like JPL.

I am uncomfortable with assuming that a military management model is best for NASA (or for a national/international space enterprise whether led by NASA or by another agency). In addition to the lack of space experience I am concerned with the mentality of military commanders as applied to what will probably be a very diverse enterprise. I recently completed a study of the management of an Air Force facility and one problem was the lack of flexibility and creativity imposed by the intrinsic "command and control" philosophy of the military.

NASA has lost many, many highly qualified people because of the downsizing frenzy in the 1990's. I believe that some of these people could be recaptured and put to good use if they saw a real chance to accomplish something in space. However, whether the current top-level management at NASA is capable of identifying and selecting the right people with the right experience is very unclear.

As we have learned at JPL, younger people can take on tremendous responsibilities and succeed. I would recommend a mix of people, like those at JPL and their contractors, who are creative, motivated, flexible and hard working be given the responsibility for implementing elements of the human exploration program. This would be facilitated by "privatizing the centers."

ANSWERS TO POST-HEARING QUESTIONS

Responses by Laurence R. Young, Apollo Program Professor, Massachusetts Institute of Technology (MIT); Founding Director of the National Space Biomedical Research Institute (NSBRI)

Questions submitted by Chairman Sherwood Boehlert

Q1. If NASA's work on the Space Station is to be completed around 2016, do you think that researchers will have learned enough about countermeasures and risks to the human body to embark on longer missions to the Moon and Mars? How much could be learned instead on missions to the Moon as envisioned by the President's exploration initiative?

A1. Yes, if we proceed with an adequate number of test subjects and follow a well-considered experimental plan with subjects who will stick with the test protocols we should learn enough by 2016 to proceed on longer interplanetary missions. The risk will be reduced, of course, by further testing, but another 12 years, with the right on-orbit equipment and adequate up-down capacity should make the risk acceptable.

As to going to the Moon first—I find that difficult to justify. Although life support systems could be tested on the Moon they could also be verified on a LEO artificial gravity craft, at lower cost and with more control. We will need to learn how to operate at Martian gravity eventually, and the lunar experience will only be of marginal benefit.

Q2. Is there a coupling between the effects of microgravity and radiation on human health while astronauts are in space or are the effects separable?

A2. I am not an expert in radiation, but can only report on the findings of others. The NRC Space Studies Board, in 2000 saw no reason to explore such coupling, and most other reports indicate no strong relationship between radiation and microgravity. However, there is some evidence from early Russian animal experiments suggesting that radiation effects were more severe during space flight than during ground experiments. This is not, in my view, a high priority issue.

Q3. In your written testimony you advocate the development of a centrifuge for humans on the Space Station, yet the centrifuge planned for the Space Station will only hold small mammals. How critical is it for NASA to develop a human centrifuge for research on the Space Station? Without a human centrifuge, will we know enough before we ask astronauts to embark on ventures beyond low-Earth orbit?

A3. Both a human centrifuge and the planned animal centrifuge are high priority items for the Space Station. In the early plans for the current animal centrifuge a second rotating arm was included, which could spin synchronously with the main wheel to exchange habitats without stopping the centrifuge. This "servicing arm" could also be adapted to spinning of astronauts for short periods of artificial gravity. The servicing arm and its human rotator capability were eliminated to reduce costs. It now seems to me that both the animal and human stimulators are absolutely necessary in order to understand and reduce to practice the artificial gravity universal antidote against the debilitating effects of weightlessness. Just as the FDA proceeds from drug testing on small animals to large animals to human clinical trials we must evaluate our countermeasure in logical steps. It must be proven in LEO before employing it on the way to Mars. The concepts and preliminary designs of such a short radius centrifuge were spelled out in a 1999 NASA–NSBRI international workshop on artificial gravity chaired by William Paloski of JSC and myself. The proposal for a flight human centrifuge ready for experiments on the ISS by 2009 has been proposed to Code U as part of the Human Research Initiative.

Q4. To what extent has the research agenda on the Space Station been limited by a lack of capacity to transport logistics, cargo, and experiments to and from the Space Station?

A4. The absence of regular Space Shuttle flights to and from the ISS and the lack of up/down capacity has already impacted the research agenda. The limited crew onboard has reduced the pace of conducting human experiments. No animal experiments can be accomplished without a glovebox on orbit and the transport of animals to and from the ISS. Several experiments have been delayed by months to years. The situation will only get worse if the Shuttle is retired in 2010 and the CEV is not operational until 2014 or later. Furthermore, the current research agenda is impacted by the inability to conduct life sciences investigations effectively immediately

post-flight research requiring access to astronauts immediately after landing is not possible when they return on a Soyuz. Additionally, the recent NRA suggests that proposals not include testing of astronauts prior to R+4, which is well beyond the critical period of re-adaptation. In my opinion, the U.S. should not abandon the Shuttle until our own next generation vehicle is operational.

Questions submitted by Representative Bart Gordon

Q1. What, if any, are your biggest concerns with respect to the President's space exploration initiative? What should Congress be focusing its attention on as we evaluate the initiative?

A1. I am in favor of the vision of human exploration of Mars. My main concerns are budget and competition for funding. Until a realistic Mars exploration plan is enunciated it is difficult to know how much this will cost and over how many years the initial development will last. However, in keeping with the President's initiative we have already begun to close down other important science and technology projects. I am also concerned about the projected lack of U.S. human launch capability between 2010 and the operation of the CEV, as discussed in my answer to Chairman Boehlert's last question.

Q2. It has been argued that one of the main rationales for human space exploration is its inspirational value. However, the Mars Pathfinder and the Spirit *and* Opportunity *Mars Rovers have demonstrated that robotic missions are capable of capturing the public imagination.*

Q2a. Given that, what do you think are the most compelling justifications for human exploration?

A2a. Robotic missions are outstanding precursors to human exploration—but they return neither the scientific nor the non-scientific value of human voyages. Many, many of my students at MIT are attracted to the space program by the human exploration challenge—either as astronauts or as explorers on the ground. Robots don't carry the same appeal. The human benefit is somewhat intangible, but it certainly motivates young people into careers in science and engineering. The opportunity for a trained human to observe, sample and form hypotheses about Mars is unlikely to be matched by robots in the foreseeable future.

Q2b. When should human exploration missions be contemplated—that is, should they be deferred until as much as possible has been accomplished robotically, or should human missions be an early goal? Why?

A2b. Human exploration should be contemplated as soon as we are confident in our countermeasures against the deleterious effects of weightlessness and radiation. They should be an early goal—but not the first goal.

Q3. What do you consider an appropriate role for the private sector to be in the exploration of the solar system?

A3. The private sector, in its traditional role of developing new technology for space exploration, should be encouraged and rewarded for technology transfer to benefit of humanity on Earth. Eventually they will be involved in space tourism, but in the near-term I believe that the direct commercial benefits of solar system exploration are limited.

Q4. One of the key questions we will have to wrestle with as we evaluate the President's proposed initiative is whether NASA has the capabilities needed to carry it out successfully. Experienced NASA personnel will be retiring just as the initiative is getting going. New employees will not have any significant experience in human space flight and will need time to acquire it. At the management levels of NASA, many of the key human space flight and exploration positions currently are held by retired generals and Admirals with no previous space-related experience.

- *How confident are you that NASA will have the experience and skills based needed to conduct the initiative safely and successfully?*
- *If you aren't, what would you recommend be done?*

A4. NASA alone currently has the experience and skills to conduct this mission. However, with the aging NASA workforce the program will have to move along smartly to recruit a new generation. The appeal of NASA will be augmented by the initiative. The new NASA scholarship program will encourage young college students to get involved. More funding to Space Grant and support of NASA Fellows

will help to renew the capable leadership. Just provide the jobs and the challenges, I believe, and the capable young people will come to accomplish the difficult tasks. We need to bring people into NASA now, however, to have them available as leaders in the next 5–10 years.

Questions submitted by Representative Nick Lampson

Q1. In your testimony you state: "the most important piece of additional equipment to meet the research goals is a short radius human centrifuge for the study of intermittent artificial gravity inside the International Space Station."

Q1a. Please explain why you feel it is so important to have a human centrifuge.

A1a. Without it we cannot explore and then demonstrate the effectiveness of artificial gravity in overcoming the deleterious effects of weightlessness on muscle, bone, cardiovascular and sensory-motor systems. And without an adequate countermeasure we dare not send astronauts on a 2–3 year mission.

Q1b. Has development of such a human centrifuge been a priority of the research community in the past, and if so, why hasn't it been included in NASA's research planning?

A1b. A human centrifuge has been called for in most if not all of the NRC Committee on Space Biology and Medicine reports since the 1970's, as well as in the reports of the various NASA advisory committees on the Space Station. It has been eliminated primarily because of cost, in favor of the smaller and cheaper animal centrifuge. There was also concern that vibration from the spinning arm would disturb the quiet environment necessary for the materials science microgravity studies.

Q1c. Addition of such a human centrifuge runs counter to NASA's current plan to limit the amount of new facilities on the Station and to bring its research activities to a close in 2016 if possible. How difficult do you think it would be to develop such a centrifuge, how long would it take, and what would it cost?

A1c. A human centrifuge would not be difficult—and feasibility studies have already been conducted. There were proposals to fly one in the Shuttle mid-deck or in Spacehab several years ago. A space flight version could be operational on the ISS by 2009. I am not qualified to estimate its cost.

Q2. The entire research program of the International Space Station has been designed around the availability of the Space Shuttle to take up and return laboratory equipment, samples, and animal and plant specimens.

- *What will be the impact on the Station's usefulness for research if the Space Shuttle is no longer available after Station assembly is completed in 2010 or soon thereafter?*
- *What would you recommend be done?*

A2. In response I repeat my answer to the similar question posed by Chairman Boehlert:

The absence of regular Space Shuttle flights to and from the ISS and the lack of up/down capacity has already impacted the research agenda. The limited crew onboard has reduced the pace of conducting human experiments. No animal experiments can be accomplished without a glovebox on orbit and the transport of animals to and from the ISS. Several experiments have been delayed by months to years. The situation will only get worse if the Shuttle is retired in 2010 and the CEV is not operational until 2014 or later. Furthermore, the current research agenda is impacted by the inability to conduct life sciences investigations effectively immediately post-flight research requiring access to astronauts immediately after landing is not possible when they return on a Soyuz. Additionally, the recent NRA suggests that proposals not include testing of astronauts prior to R+4, which is well beyond the critical period of readaptation. In my opinion, the U.S. should not abandon the Shuttle until our own next generation vehicle is operational.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Lennard A. Fisk, Chair, Space Studies Board (SSB), National Academy of Sciences; Chair, Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan; Former Associate Administrator, Space Science and Applications, NASA

Questions submitted by Chairman Sherwood Boehlert

Q1. To the best of your knowledge, are there alternative "end states" to assembly of the Space Station other than that which NASA currently plans that would meet all or most of our international commitments, would require less expenditures of funding, and would still allow the necessary science to be conducted on the effects of space on human physiology?

A1. I am not aware of such alternative end states. Our commitments to ESA and Japan, to provide for their use of the Columbus module and Japan Experiment Module (JEM) for their research programs, will require us to complete the basic ISS assembly. We would have to be relieved of this obligation to follow another course. Moreover, the NASA exploration initiative will require biomedical data on crew performance in microgravity, as well as the development of technology in support of exploration, all of which requires a capable space station.

Q2. At the hearing, you recommended that NASA proceed step by step with the exploration initiative to "learn as you go." What do you believe are the significant steps that NASA must take as it implements the initiative, and what kind of milestones or gates do you believe, if any, Congress should set to ensure that the initiative is proceeding well and NASA is properly learning as it is going?

A2. The first step should be to develop a relatively detailed architecture, which will specify the technology needed, robotic missions required, and how all these elements will be integrated in support of the exploration initiative.[1] This is a major effort. NASA appears to be undertaking this now. However, I would encourage the agency to involve the broader scientific and industrial community. One of the lessons from the science program is that it feeds on the creative tension that exists between NASA and the broader science community.[2] The human space flight program could do well to develop its own creative tension.

With an architectural plan in place, milestones and decision points can then be specified. It would be unwise at this point to attempt to specify in detail how we will get to Mars, or even what it would cost. These cannot be determined today. Rather, we should ask what the first steps are within a likely architecture, and how they will provide options for the next steps and so on, and measure our progress through accomplishing these successive steps.

Q3. Steven Weinberg recently wrote an article in The New York Review of Books *entitled "The Wrong Stuff" (see attachment) in which he says that "as the Moon and Mars missions absorb more and more money, the golden age of cosmology is going to be terminated."*

Do you agree with Dr. Weinberg's assessment? How can Congress ensure that any cost growth for infrastructure does not adversely effect funding for science, especially if Congress is unable to provide NASA as a whole with greater funding?

A3. Termination is an unlikely possibility. An intellectual issue as basic and as vibrant as current cosmology cannot be killed. Rather, the issue is balance within the science program. It has long been a policy of space science to attempt, within available resources, to have each of the major science disciplines advance at a reasonable pace. All of the major science disciplines are judged to be important for understanding the universe in which we live. The exploration mission threatens that balance by declaring some science disciplines to be more important for exploration than others, such as cosmology. We should all, the science community and Congress, encourage NASA not to distinguish among its science disciplines, but rather to develop and execute plans that allow each to progress as expeditiously as resources allow.

[1] National Research Council, *Issues and Opportunities Regarding the U.S. Space Program: A Summary Report of a Workshop on National Space Policy.* National Academies Press, Washington, D.C., 2004, p. 35.

[2] National Research Council, *Issues and Opportunities Regarding the U.S. Space Program: A Summary Report of a Workshop on National Space Policy.* National Academies Press, Washington, D.C., 2004, pp. 1, 38.

Q4. What recommendations, if any, would you make on how best to organize NASA to undertake the President's space exploration initiative?

A4. I would not like to comment in any detail on the NASA organization. The Presidential Commission on Moon, Mars and Beyond is expected to offer advice here. One general comment, however: NASA has many missions, of which exploration, as they now define it, is only one. An organizational structure has to be found that allows each of NASA's missions to succeed, while encouraging as much integration of activities across the agency as possible.

Q5. We are now totally dependent on the Russians to provide crew rescue with their Soyuz vehicles. However, Russia fulfills its Soyuz obligations to the international partners in April 2006. After that time, it is not clear how NASA plans to provide a crew rescue capability for astronauts on-board the Space Station.

- *Do you believe NASA should develop its own crew rescue capsule for the Space Station? How soon do you think a crew rescue capsule could be developed?*
- *Do you believe that the Crew Exploration Vehicle should be designed to service the Space Station as well as carry out missions beyond low-Earth orbit?*

A5. There are numerous choices here. The crew rescue vehicle is important for providing the maximum possible crew for the ISS, which in turn is necessary to achieve the scientific research on the ISS, particularly the biomedical research that will be necessary for the exploration initiative. The Soyuz, or perhaps more correctly multiple Soyuz vehicles can provide this, if we are willing to depend on and support the Russians. A separate U.S. crew rescue vehicle would be desirable. However, if it is to be developed separately, it could distract from the Crew Exploration Vehicle development that will be required to proceed with the initiative. Conversely, if the Crew Exploration Vehicle is designed also to serve as the crew rescue vehicle, there is a danger that it will be another example of promising too many capabilities for one development, which is a mistake NASA has made in previous developments, especially the Shuttle and the ISS.

I believe this is yet another example of the necessity of a good architecture study for the exploration initiative, which should indicate what capabilities it is reasonable to expect of the Crew Exploration Vehicle. Following that determination, it should be possible to specify the options for the crew rescue vehicle, and decide whether there are any that are both technically and politically acceptable.

Questions submitted by Representative Bart Gordon

Q1. What, if any, are your biggest concerns with respect to the President's space exploration initiative? What should Congress be focusing its attention on as we evaluate the initiative?

A1. Let me start by saying that I am very supportive of the exploration initiative. I believe it defines realistic and realizable goals for human space flight. However, I do have concerns:

Foremost among the concerns is the arbitrary bifurcation of science into disciplines that are judged to be supportive of exploration and those that are not, the so-called "other science." I consider this split to be arbitrary and not based on any defendable argument. For example, Sun-Earth Connection, one of the science themes in NASA's Office of Space Science, is clearly important for human exploration since it is concerned with the radiation environment of space; yet much of it is designated "other science." The Structure and Evolution of the Universe theme, also labeled as "other science," is concerned with basic cosmology, and this is certainly exploration. Earth science has a mandate all its own. I would eliminate this arbitrary division, and provide for the balanced science program that has been so successful throughout the history of the space program.

I am also concerned that NASA is not reaching out adequately in its effort to develop an architectural design of the new exploration initiative. The ongoing studies of how to pursue this bold venture should involve the broader space community in the U.S. industry and academia—and also engage our international partners. Broadening that activity will result in a better design, as well as broader political support.

Q2. It has been argued that one of the main rationales for human space exploration is its inspirational value. However, the Mars Pathfinder and the Spirit *and* Opportunity *Mars Rovers have demonstrated that robotic missions are capable of capturing the public imagination.*

- *Given that, what do you think are the most compelling justifications for human exploration?*
- *When should human exploration missions be contemplated—that is, should they be deferred until as much as possible has been accomplished robotically, or should human missions be an early goal? Why?*

A2. It is a judgment call as to whether we can derive as much inspirational value from robots as we can from human presence. My personal judgment is we cannot. Humans relate to other humans; humans can communicate the experience. You can drive auto-racing cars remotely. Do you think it would be as interesting to the public if all the drivers sat in the stands with remote control devices?

I would also argue that we should expect that in time, hopefully within the next century, we will extend our civilization into the solar system. The human presence will be extended to other planets. The only issue for now, then, is when do we start and who leads it? The exploration initiative is intended to do that.

That said, for the exploration of Mars both humans and robots will be necessary, working in synergy—human-assisted robots and robot-assisted humans. Robots clearly need to go first. The delay time for communication between Earth and Mars will eventually require, at minimum, humans to be located in Mars orbit to direct robotic exploration. And then humans need to be on the surface of Mars using their reasoning skills to maximize the scientific return.

Q3. What do you consider an appropriate role for the private sector to be in the exploration of the solar system?

A3. Exploration of this type will always be a governmental function, just as Columbus' voyages were, and Lewis and Clark's. However, the execution of this program will fall to industry and academia to accomplish. NASA does not build rockets, or for that matter most satellites, and American industry will have to step up to these tasks, just as they did during the Apollo program.

Q4. One of the key questions we will have to wrestle with as we evaluate the President's proposed initiative is whether NASA has the capabilities needed to carry it out successfully. Experienced NASA personnel will be retiring just as the initiative is getting going. New employees will not have any significant experience in human space flight and will need time to acquire it. At the management levels of NASA, many of the key human space flight and exploration positions currently are held by retired generals and Admirals with no previous space-related experience.

- *How confident are you that NASA will have the experience and skills based needed to conduct the initiative safely and successfully?*
- *If you aren't, what would you recommend be done?*

A4. First of all, I think it is important to recognize that questions about the required skills and capabilities to carry out the exploration initiative are not just a NASA problem, but rather a problem throughout the space industry. Many of our best space engineers and scientists, in industry and at universities, entered the space program or were inspired to do so during the Apollo era. They are now at the end of their careers.

The workforce necessary for a sustained program leading to a human mission to Mars does not now exist. In simple terms, by the time we are ready to send a human to Mars we will need 50,000 to 75,000 new space engineers and scientists.

The task of providing this workforce will fall to American universities. NASA should thus make providing the required workforce an integral part of its planning for the new initiative and be concerned with and assist the university community in performing its essential role.

It is important to note that this issue is not simply about encouraging K–12 students to pursue math and science. The workforce needed for the exploration initiative is small compared to the Nation's expected output of engineers and scientists. Rather, the issue is encouraging the best and the brightest to pursue careers in space. Students often make career decisions as undergraduates, which again emphasizes the important role that universities will have to play in the new space initiative.

Questions submitted by Representative Nick Lampson

Q1. As NASA Associate Administrator for space science you had direct influence on many of NASA's current robotic missions. The Hubble Space Telescope is the most direct example of a successful integration of human and robotic space ac-

tivities. There was also the case where the crew of STS–41C repaired the Solar Maximum Mission satellite in orbit. To what extent should future space telescopes be designed for long-term operation and periodic servicing by humans?

A1. The Hubble Space Telescope is certainly an excellent example of integrated robotic and human space activities. Without Shuttle repair and servicing, Hubble would have been a great disappointment, rather than the outstanding success it has become.

As for future missions involving human servicing, the NRC plans to pursue a study of Large Optical Systems in Space. The study will examine the goals of large telescopes in space across many agency needs and consider factors of location, infrastructure, assembly, operations, and servicing.

Q2. What, if any, scientific activities on the Moon will require the presence of astronauts? What priority does the scientific community assign to those scientific activities relative to other potential space science projects?

A2. The primary reason for going back to the Moon will probably be to practice for sending humans to Mars. Science can be done, and the presence of humans can facilitate that science. However, science exploration of the Moon can probably also be done robotically.

Particularly ambitious goals for the Moon, e.g., setting up astronomical observatories, that would require humans are worthy of further study.

NRC reports have not dealt with lunar science in recent years, since the thrust of solar system exploration has been Mars and the other planets and small bodies. It would be worthwhile to re-examine the goals of lunar science in light of the Moon as an immediate destination for both the robotic and human space flight program.

Attachment

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Email to a friend

Feature

The Wrong Stuff

By Steven Weinberg

1.

Ever since NASA was founded, the greater part of its resources have gone into putting men and women into space. On January 14 of this year, President Bush announced a "New Vision for Space Exploration" that would further intensify NASA's concentration on manned space flight. The International Space Station, which has been under construction since 1998, would be completed by 2010; it would be kept in service until around 2016, with American activities on the station from now on focused on studies of the long-term effects of space travel on astronauts. The manned spacecraft called the space shuttle would continue flying until 2010, and be used chiefly to service the space station. The shuttle would then be replaced by a new manned spacecraft, to be developed and tested by 2008. Between 2015 and 2020 the new spacecraft would be used to send astronauts back to the moon, where they would live and work for increasing periods. We would then be ready for the next step—a human mission to Mars.

This would be expensive. The President gave no cost estimates, but John McCain, chairman of the Senate Commerce, Science, and Transportation Committee, has cited reports that the new initiative would cost between $170 billion and $600 billion. According to NASA briefing documents, the figure of $170 billion is intended to take NASA only up to 2020, and does not include the cost of the Mars mission itself. After the former President Bush announced a similar initiative in 1989, NASA estimated that the cost of sending astronauts to the moon and Mars would be either $471 billion or $541 billion in 1991 dollars, depending on the method of calculation. This is roughly $900 billion in today's dollars. Whatever cost may be estimated by NASA for the new initiative, we can expect cost overruns like those that have often accompanied big NASA programs. (In 1984 NASA estimated that it would cost $8 billion to put the International Space Station in place, not counting the cost of using it. I have seen figures for its cost so far ranging from $25 billion to $60 billion, and the station is far from finished.) Let's not haggle over a hundred billion dollars more or less—I'll estimate that the President's new initiative will cost nearly a trillion dollars.

Compare this with the $820 *million* cost of recently sending the robots *Spirit* and *Opportunity* to Mars, roughly one thousandth the cost of the President's initiative. The inclusion of people inevitably makes any space mission vastly more expensive. People need air and water and food. They have to be protected against cosmic rays, from which we on the ground are shielded by the Earth's atmosphere. On a voyage to Mars astronauts would be beyond the protective reach of the Earth's magnetic field, so they would also have to be shielded from the charged particles that are sent out by the sun during solar flares. Unlike robots, astronauts will want to return to Earth. Above all, the tragic loss of astronauts cannot be shrugged off like the loss of robots, so any casualties in the use of the new spacecraft would cause costly delays and alterations in the program, as happened after the disastrous accidents to the *Challenger* shuttle in 1986 and to the *Columbia* shuttle in February 2003.

The President's new initiative thus makes it necessary once more to take up a question that has been with us since the first space ventures: What is the value of sending human beings into space? There is a serious conflict here. Astronomers and other scientists are generally skeptical of the value of manned space flight, and often resent the way it interferes with scientific research. NASA administrators, astronauts, aerospace contractors, and politicians typically find manned space flight just wonderful. NASA's Office of Space Science has explained that "the fundamental goal of the President's Vision is to advance US scientific, security, and economic interests through a robust space exploration program." So let's look at how manned space flight advances these interests.

2.

Many Americans remember the fears for US national security that were widely felt when the Soviets launched the unmanned Sputnik satellite in October 1957. These fears were raised to new heights in 1961, when the Soviet cosmonauts Yuri Gagarin and then Gherman Titov went into space. Titov's spacecraft made seventeen orbits around the Earth, three of them passing for the first time over the United States. The American reaction is described by Tom Wolfe in *The Right Stuff*:

> Once again, all over the country, politicians and the press seemed profoundly alarmed, and the awful vision was presented; suppose the cosmonaut were armed with hydrogen bombs and flung them as he came over, like Thor flinging thunderbolts.... Toledo disappears off the face of the earth ...Kansas City...Lubbock....

As it turned out, the ability to send rockets into space did have tremendous military importance. Ballistic missiles that travel above the Earth's atmosphere all but replaced bombers as the vehicle of choice for carrying Soviet or American nuclear weapons to an adversary's territory. Even in the nonnuclear wars of today, artificial satellites in orbit around the Earth play an essential part in surveillance, communications, and navigation. But these missiles and satellites are all unmanned. One can't just drop bombs from satellites to the Earth's surface— once something is put in orbit above the

Earth's atmosphere, it stays in orbit unless a rocket brings it down. As far as I know there never has been a moment from Titov's flight to the present when the ability to put people into space gave any country the slightest military advantage.

I say this despite the fact that some military satellites have been put into orbit by the space shuttle. This could be done just as well and much more cheaply by unmanned rockets. It had been hoped that the shuttle, because reusable, would reduce the cost of putting satellites in orbit. Instead, while it costs about $3,000 a pound to use unmanned rockets to put satellites in orbit, the cost of doing this with the shuttle is about $10,000 a pound. The physicist Robert Park has pointed out that at this rate, even if lead could be turned into gold in orbit, it would not pay to send it up on the shuttle. Park could have added that in this case NASA would probably send lead bricks up on the shuttle anyway, and cite the gold in press releases as proof of the shuttle's value. There doesn't seem to have been any reason for the use of the shuttle to take some military satellites into orbit other than that NASA has needed some way to justify the shuttle's existence. During the Carter administration, NASA explained to the deputy national security adviser that unless President Carter forced military satellite missions onto the space shuttle it would be the President who would be responsible for the end of the shuttle program, since the shuttle could never survive if it had to charge commercial users the real cost of space launches.

3.

Similar remarks apply to the direct economic benefits of space travel. There is no doubt about the great value of artificial satellites in orbit around the Earth. Those that survey the Earth's surface give us information about weather, climate, and environmental change of all sorts, as well as warnings of military buildups and rocket launches. Satellites relay television programs and telephone conversations beyond the horizon. The Global Positioning System, which calculates the location of automobiles, ships, and planes, as well as missiles, relies on the timing of signals from satellites. But again, these are all unmanned satellites, and can be put into orbit most cheaply by unmanned rockets.

It is difficult to think of any direct economic benefit that can be gained by putting people into space. There has been a continuing effort to grow certain crystals in the nearly zero gravity on an orbiting satellite such as the International Space Station, or to make ultra-pure semiconductor films in the nearly perfect vacuum in the wake of the space station. Originally President Reagan approved the space station in the expectation that eventually it could be run at a profit. Nothing of economic value has come of this, and these programs have now apparently been wisely abandoned in the President's new plans for the space station.

Lately there has been some talk of sending astronauts to mine the light isotope helium three on the moon, where it has been deposited through billions of years of exposure of the moon's surface to the solar wind. The point is that the more familiar thermonuclear reactions that use hydrogen isotopes as fuel produce large numbers of

neutrons, which could damage surrounding materials and make them radioactive, while thermonuclear reactions involving helium three produce far fewer neutrons, and hence less radioactive waste. A thermonuclear reactor using helium three might also allow a more efficient conversion of nuclear energy to electricity, if it could be made to work.

Unfortunately, that is a big "if." One of the things that makes the development of thermonuclear power so difficult is the necessity of heating the fuel to a very high temperature so that atomic nuclei can collide with each other with enough velocity to overcome the repulsive forces between the electric charges carried by the nuclei. Helium nuclei have twice the electric charge of hydrogen nuclei, so the temperature needed to produce thermonuclear reactions involving helium three and hydrogen isotopes is much higher than the temperature needed for reactions involving hydrogen isotopes alone. So far, no one has been able to produce a useful, self-sustaining thermonuclear reaction using hydrogen isotopes. Until that is done, there seems little point in going to great expense on the moon to mine a fuel whose use would make it even more difficult to generate thermonuclear power.

In his speech on January 14 President Bush emphasized that the space program produces "technological advances that have benefited all humanity." It is true that pursuing a demanding task like putting men on Mars can yield indirect benefits in the form of new technologies, but here too I think that unmanned missions are likely to be more productive. Trying to think of some future spinoff from space missions that would really benefit humanity, I find it hard to come up with anything more promising than the experience of designing robots that are needed for unmanned space missions. This experience can help us in building robots that can spare humans from dangerous or tedious jobs here on Earth. Surprises are always possible, but I don't see how anything of comparable value could come out of developing the specialized techniques needed to keep people alive on space missions.

4.

President Bush's presentation of his space initiative emphasized the scientific knowledge to be gained. Some readers of his speech may imagine astronauts on the shuttle or the space station peering through telescopes at planets or stars, or wandering about on the moon or Mars making discoveries about the history of the solar system. It doesn't work that way.

There is no question that observatories in space have led to a tremendous increase in astronomical knowledge. To take just one example, in the early 1990s instruments on the Cosmic Background Explorer satellite made measurements of a faint background of microwave radio static that had been discovered in 1965. This radiation is left over from a time when the universe was only about four hundred thousand years old. The new data showed that the intensity of this radiation at various wavelengths was just what would be emitted by opaque matter at a temperature of 2.725 degrees Celsius above absolute zero. It was the first time in the history of cosmology that *anything* had

been measured to four significant figures. More important, the intensity of this radiation was found to be not perfectly uniform, but slightly lumpy. The observed intensity differs from one part of the sky to another by roughly one part in a hundred thousand for directions separated by a few degrees of arc. This amount of lumpiness is just what was expected, on the assumption that these variations in the cosmic microwave background arose from quantum fluctuations in the spatial distribution of energy in the very early universe, fluctuations that also eventually gave rise to the concentrations of matter—galaxies and clusters of galaxies—that astronomers see throughout the universe.

There followed a decade of increasingly refined observations of the cosmic microwave background from mountaintops, balloons, and the South Pole, but the distorting effect of the Earth's atmosphere sets a limit to the precision that can be obtained with measurements from even the highest altitudes accessible to balloons. Finally these studies were dramatically advanced in 2002 by a remarkable new space mission, the Wilkinson Microwave Anisotropy Probe. After making repeated loops around the Earth to build up speed, this probe traveled out to a point in space known as L2, about a million miles from the Earth (four times farther than the moon), in the direction opposite from the Sun. Anything placed at L2 orbits the Sun at just the speed needed to keep it at L2. There, in the cold quiet of interplanetary space, it was possible to map out the lumpiness of the cosmic microwave radiation background to an unprecedented level of accuracy. The comparison of these measurements with theory has confirmed our general ideas about the emergence of fluctuations in the very early universe; it has shown that the universe now consists of about 4 percent ordinary atoms, about 23 percent dark matter of some exotic type that does not interact with radiation, and the rest some sort of mysterious "dark energy" having negative pressure; and it has given the age of the universe as between 13.5 billion and 13.9 billion years.

Exciting research, of which NASA may justly feel proud. Research of this sort has made this a golden age for cosmology. But neither the Cosmic Microwave Background Explorer nor the Wilkinson Microwave Anisotropy Probe had any astronauts aboard. People were not needed. On the contrary, through their movements and body heat they would have fouled up these measurements, as well as greatly increasing the cost of these missions. The same is true of every one of the space observatories that have expanded our knowledge of the universe through observations of ultraviolet light, infrared light, X-rays, or gamma rays from above the Earth's atmosphere. Some of these observatories were taken into orbit by the shuttle, while others (including the Cosmic Microwave Background Explorer and the Wilkinson Microwave Anisotropy Probe) were carried up by unmanned rockets, as all of them could have been.

The Hubble Space Telescope is a special case. Like the other orbiting observatories, the Hubble operates under remote control, with no people traveling with it. But unlike

these other observatories, the Hubble was not only launched by the shuttle, but has also been serviced several times by astronauts brought up to its orbit by the shuttle. The Hubble has made a great contribution to astronomy, one that goes way beyond taking gorgeous color photos of planets and nebulae. Most dramatically, teaming up with observatories on the ground, the Hubble carried out a program of measuring the distances and velocities of far-away galaxies. In 1998 these measure- ments revealed that the expansion of the universe is not being slowed down by the mutual gravitational attraction of its matter, as had been thought, but is rather *speeding up*, presumably in response to the gravitational repulsion of the dark energy I mentioned earlier. The Hubble may have given NASA its best argument for the scientific value of manned space flight.

But like the other space observatories, the Hubble Space Telescope could have been carried into orbit by unmanned rockets. This would have spared astronauts the danger of shuttle flights, and it would have been much cheaper. Riccardo Giacconi, the former director of the Space Telescope Science Institute, has estimated that by using unmanned rockets instead of the space shuttle, we could have sent up seven Hubbles without increasing the total mission cost. It would then not have been necessary to service the Hubble; when design flaws were discovered or parts wore out, we could just have sent up another Hubble.

What about the scientific experiments done by astronauts on the space shuttle or the space station? Recently I asked to see the list of experiments that NASA assigned to the astronauts aboard the *Columbia* space shuttle on its last flight, which ended tragically when the shuttle exploded during re-entry. It is sad to report that it is not an impressive list of experiments. Roughly half had to do with the effect of the space environment on the astronauts. This at least is a kind of science that cannot be done without the presence of astronauts, but it has no point unless one plans to put people into space for long periods for some other reason.

Of the other half of the *Columbia*'s experiments, a large fraction dealt with the growth of crystals and the flow of fluids in nearly zero gravity, old standbys of NASA that have neither illuminated any fundamental issues of science nor led to any practical applications. It is always dangerous for a scientist in one field to try to judge the value of work done by specialists in other fields, but I think I would have heard about it if anything really exciting was coming out of any of these experiments, and I haven't. Much of the "scientific" program assigned to astronauts on the space shuttle and the space station has the flavor of projects done for a high school science talent contest. Some of the work looks interesting, but it is hard to see why it has to be done by people. For instance, there was just one experiment on *Columbia* devoted to astronomy, a useful measurement of variations in the energy being emitted from the sun. The principal investigator tells me that the only intervention of the astronauts consisted of turning the apparatus on and then turning it off.

Looking into the future, we need to ask, what scientific work can be done by astronauts on Mars? They can walk around and look at the terrain, and carry out tests on rocks, looking for signs of water or life, but all that can be done by robots. They can bring back rock samples, as the Apollo astronauts did from the moon, but that too can be done by robots. Samples of rocks from the moon were also brought back to Earth by unmanned Soviet lunar missions. It is sometimes said that the great disadvantage of using robots in a mission to Mars is that they can only be controlled by people on Earth with a long wait (at least four minutes) for radio signals to travel each way between the Earth and Mars. That would indeed be a severe problem if the robots were being sent to Mars to play tennis with Martians, but not much is happening there now, and I don't see why robots can't be left to operate with only occasional intervention from Earth. Any marginal advantage that astronauts may have over robots in exploring Mars would be more than canceled by the great cost of manned missions. For the cost of putting a few people in a single location on Mars, we could have robots studying many different landscapes all over the planet.

5.

Many scientists and some NASA administrators understand all this very well. I have frequently been told that it is necessary publicly to defend programs of manned space flight anyway, because the voters and their elected representatives only care about the drama of people in space. (Richard Garwin has reminded me of the old astronauts' proverb "No bucks without Buck Rogers.") It is hoped that while vast sums are being spent on manned space flight missions, a little money will be diverted to real science. I think that this attitude is self-defeating. Whenever NASA runs into trouble, it is science that is likely to be sacrificed first. After NASA had pushed the Apollo program to the point where people stopped watching lunar landings on television, it canceled Apollo 18 and 19, the missions that were to be specifically devoted to scientific research.

It is true that the administration now projects a 5 percent increase per year in NASA's funding for the next three years. So far, funding is being maintained for the next large space telescope, and is being increased for some other scientific programs, including robotic missions to the planets and their moons. But we can already see damage to programs that are not related to exploration of the solar system, and especially to research in cosmology. Studying the origin of the planets is interesting, but certainly not more so than studying the origin of the universe.

Two days after President Bush presented his new space initiative, NASA announced that the planned shuttle mission to service Hubble in 2006 would be canceled. This mission would have replaced gyroscopes and batteries that are needed to extend Hubble's life into the next decade, and it would have installed two new instruments (which have already been built, at a cost of $167 million) to extend Hubble's capacities. One of these instruments would have allowed Hubble to survey the sky in infrared and ultraviolet light, revealing much about the formation of the earliest stars and galaxies. The other was an ultraviolet spectrograph, which would have explored

intergalactic matter in the early universe. Using older instruments, Hubble would also have pushed the program of measuring distances and velocities of galaxies to greater distances, mapping out the dark energy that is accelerating the expansion of the universe. Instead, in about three years, when the Hubble gyroscopes can no longer point the telescope accurately, it will cease operation. This will leave us with no large space telescope until 2011 at the earliest. Eventually, before the slight drag of the Earth's atmosphere at its altitude can bring the Hubble down, an unmanned rocket will be sent up to the Hubble to take it out of orbit and deposit it harmlessly into the ocean. Part of the increase in NASA's spending for science will be about $300 million for destroying Hubble.

NASA's stated reason for terminating the Hubble while continuing work on the space station is that it is more dangerous for the shuttle to go up to Hubble than to the space station. Supposedly, if the astronauts on the shuttle find that damage has been done to the shuttle's protective tiles during launch, they could wait in the space station for a rescue, while this would not be possible during a mission to the Hubble. But there are many other dangers to astronauts that are the same whether the shuttle is going to the space station or the Hubble Space Telescope. Among these is an explosion during launch, like the one that destroyed the *Challenger* shuttle in 1986. The *New York Times* Web site has carried a report from an anonymous NASA engineer who challenges NASA's statement that a shuttle flight to Hubble would be more risky than a flight to the space station. He or she points out that the shuttle would be less exposed to micrometeoroids and orbital debris at the altitude of Hubble than at the lower altitude of the space station.

Even if one considers only the possibility of damage to the shuttle's protective tiles, there may not be much difference in the risks of going to Hubble or the space station. The Columbia Accident Investigation Board discussed this safety problem, but it recommended that NASA develop the ability to repair the shuttle's tiles in space, whether or not it is docked to the space station, and it did not conclude that the Hubble had to be abandoned. To be reasonably sure of rescuing the astronauts even if it turns out that damage to the shuttle can't be repaired in space, it could be arranged at some extra cost that when one shuttle goes up to service Hubble, the other shuttle will be kept ready on the ground. For instance, the Hubble servicing mission could be scheduled just before one of the planned missions to the space station. In response to pressure from Congress and the scientific community, NASA has agreed to reconsider this decision. I don't know enough about questions of safety to judge this issue myself, but I share the widespread suspicion that Hubble is being sacrificed to save funds for the President's initiative, and in particular in order to reserve all flights on the shuttle's limited schedule for the one purpose of taking astronauts to and from the space station.

Perhaps because of its timing, the Hubble decision attracted great public attention, but there are other recent NASA decisions that have nothing to do with safety, and that

therefore give clearer evidence of the willingness of NASA and the administration to sacrifice science to save money for manned space flight. In January 2003, after several years of scientists' making difficult decisions about their priorities, NASA announced a new initiative, called Beyond Einstein, to explore some of the more exotic phenomena predicted by Einstein's General Theory of Relativity. This includes a satellite (to be developed jointly with the Department of Energy) that would look at many more galaxies at great distances, in order to uncover the nature of the dark energy by finding whether its density has been changing as the universe expands. Equally important for cosmology, there would be another probe that would study the polarization of the cosmic microwave background to find indirect effects of gravitational waves from the early universe. (Gravitational waves bear the same relation to ordinary gravity that light waves bear to electric and magnetic fields—they are self-sustaining oscillations in the gravitational field, which propagate through empty space at the speed of light.)

Beyond Einstein also includes another satellite dedicated to searching for black holes, and two larger facilities. One is an array of X-ray telescopes called Constellation-X, which would observe matter falling into black holes. The other is called LISA, the Laser Interferometer Space Antenna. This "antenna" would consist of three unmanned spacecraft in orbit around the sun, separated from each other by about three million miles. Changes in the distances between the three spacecraft would be continually measured with a precision better than a millionth of an inch by combining laser beams passing between them. These exquisite measurements would be able to reveal the presence of gravitational waves passing through the solar system. LISA would have enough sensitivity to detect gravitational waves produced by stars being torn apart as they fall into black holes or by black holes merging with each other, events we can't see with ordinary telescopes. NASA has another particularly cost-effective program called Explorer, which has supported small and mid-sized observatories like the Cosmic Background Explorer and Wilkinson Microwave Anisotropy Probe.

Alas, NASA's Office of Space Science has now announced that the Beyond Einstein and Explorer programs "do not clearly support the goals of the President's Vision for space exploration," so their funding has been severely reduced. Funding for the three smaller Einstein missions has been put off for five years; LISA will be deferred for a year or more; Explorer will be reduced in scope for the next five years; and no proposals for new Explorer missions will be considered for one or two years. None of this damage is irreparable, but spending on the President's "New Vision" has barely begun. These deferrals, along with the end of Hubble servicing, are warnings that as the moon and Mars missions absorb more and more money, the golden age of cosmology is going to be terminated, in order to provide us with the spectacle of people going into space for no particular reason.

6.

When advocates of manned space flight run out of arguments for its contribution to "scientific, security, and economic interests," they invoke the spirit of exploration, and

talk of the Oregon Trail (Bush I) or Lewis and Clark (Bush II). Like many others, I am not immune to the excitement of seeing astronauts walking on Mars or the moon. We have walked on Mars so often in our reading—with Dante and Beatrice, visiting the planet of martyrs and heroes; with Ray Bradbury's earthmen, finding ruins and revenants of a vanished Martian civilization; and more recently with Kim Stanley Robinson's pioneers, transforming Mars into a new home for humans. I hope that someday men and women will walk on the surface of Mars. But before then, there are two conditions that will need to be satisfied.

One condition is that there will have to be something for people to do on Mars which cannot be done by robots. If a few astronauts travel to Mars, plant a flag, look at some rocks, hit a few golf balls, and then come back, it will at first be a thrilling moment, but then, when nothing much comes of it, we will be left with a sour sense of disillusion, much as happened after the end of the Apollo missions. Perhaps after sending more robots to various sites on Mars something will be encountered that calls for direct study by humans. Until then, there is no point in people going there.

The other necessary condition is a reorientation of American thinking about government spending. There seems to be a general impression that government spending harms the economy by taking funds from the private sector, and therefore must always be kept to a minimum. Unlike what is usually called "big science"—orbiting telescopes, particle accelerators, genome projects—sending humans to the moon and Mars is so expensive that, as long as the public thinks of government spending as parasitic on the private economy, this program would interfere with adequate support for health care, homeland security, education, and other public goods, as it has already begun to interfere with spending on science.

My training is in physics, so I hesitate to make pronouncements about economics; but it seems obvious to me that for the government to spend a dollar on public goods affects total economic activity and employment in just about the same way as for government to cut taxes by a dollar that will then be spent on private goods. The chief difference is in the kind of goods produced by the economy—public or private. The question of what kind of goods we most need is not one of economic science but of value judgments, which anyone is competent to make. In my view the worst problem facing our society is not that there is a scarcity of private goods—food or clothing or SUVs or consumer electronics—but rather that there are sick people who cannot get health care, drug addicts who cannot get into rehabilitation programs, ports vulnerable to terrorist attack, insufficient resources to deal with Afghanistan and Iraq, and American children who are being left behind. As Justice Holmes said, "Taxes are what we pay for civilized society." But as long as the public is so averse to being taxed, there will be even less money either to ameliorate these societal problems or to do real scientific research if we spend hundreds of billions of dollars on sending people into space.

7.

In the foregoing, I have taken the President's space initiative seriously. That may be a mistake. Before the "New Vision" was announced, the administration was faced with the risk of political damage from a possible new fatal shuttle accident like the *Columbia* disaster less than a year earlier. That problem could be eased by canceling all shuttle flights before the 2004 presidential election, and allowing only enough flights after that to keep building the space station. The space station posed another problem: no one was excited any more by what had become the Great Orbital Turkey. While commitments to domestic contractors and international partners protected it from being immediately scrapped, its runaway costs needed to be cut. But just cutting back on the shuttle and the space station would be too negative, not at all in keeping with what might be expected from a President of Vision. So, back to the moon, and on to Mars! Most of the huge bills for these manned missions would come due after the President leaves office in 2005 or 2009, and the extra costs before then could be covered in part by cutting other things that no one in the White House is interested in anyway, like research on black holes and cosmology. After the end of the President's time in office, who cares? If future presidents are not willing to fund this initiative then it is they who will have to bear the stigma of limited vision. So, looking on the bright side, instead of spending nearly a trillion dollars on manned missions to the moon and Mars we may wind up spending only a fraction of that on nothing at all.